CELESTIAL MOTIONS

A HANDY BOOK OF

ASTRONOMY

W. T. LYNN

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OF

ASTRONOMY.

COMPARATIVE SIZES OF THE SUN & PRINCIPAL PLANETS.

Mercury ☿, Venus ♀, and Mars ♂, drawn to same scale, would be mere dots, being smaller than the Earth.

S U N

CELESTIAL MOTIONS:

A
HANDY BOOK
OF

ASTRONOMY.

BY
WILLIAM THYNNE LYNN,
B.A., F.R.A.S.
FORMERLY OF THE ROYAL OBSERVATORY, GREENWICH.

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PREFACE.

THIS little treatise is not intended in any way as a substitute for other and larger works on astronomy. But the author was induced to think that a concise digest of the most important facts which have been discovered regarding the motions of the celestial bodies, and the dimensions of those belonging to our own system, might be useful to many persons who take an interest in the science. Particular care has been exerted to render the information given the most recent which is available at the time of publication.

Blackheath,
March 1st, 1884.

W. T. L.

The second edition has been thoroughly revised, and the information brought up to its date.

Blackheath,
July 1st, 1884.

W. T. L.

"Lift up your eyes on high, and behold Who hath created these things, that bringeth out their host by number; He calleth them all by names by the greatness of His might, for that He is strong in power; not one faileth."—*Isaiah* xl. 26.

"Laudate eum, Harmoniæ cœlestes."—*Kepler.*

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CELESTIAL MOTIONS.

I. THE EARTH.

THE Earth being the place of our habitation, we know much more respecting it than we can ever do concerning the other bodies of the universe, even those of the solar system, which belong, so to speak, to the same family, deriving their light and heat from the same source, round which they all revolve. But as we do not propose in this brief sketch to touch at all upon the physical condition of any of those bodies, confining ourselves to their motions and (so far as these can be known) to their dimensions, the only essential difference made by the superior knowledge thus attainable by us in reference to the earth consists in the much higher degree of accuracy of which it is susceptible.

The form, then, of this our planet is very nearly, but not quite, spherical, being slightly flattened at the poles, the diameter taken anywhere across the equator measuring about 7926 miles, and the polar diameter, or that taken from pole to pole, about 7899 miles, twenty-seven less than the equatorial. The equator,

however, is not exactly circular, but somewhat elliptical in form; according to the latest determination, by Colonel A. R. Clarke, its longer axis (which meets the surface in points at longitude respectively 8° 15′ east, and 171° 45′ west, of Greenwich) is 7926·754 miles in length, and the shorter 7926·176, whilst the Earth's polar diameter is 7899·394 miles.

With regard to the motions of the Earth, and first to its diurnal rotation. Its axis is inclined at an angle of 66° 32′ to the plane of its orbit; and it turns round this axis in a space of 23 hours 56 minutes 4 seconds ·09, which is called a **sidereal** day. But the day of our ordinary reckoning is a **solar** day, for the convenience of life renders it necessary to regulate our time by the Sun, and in consequence of the Earth's annual motion round that body, the period of revolution between two successive similar relative positions is a little longer than that between two successive similar positions relatively to the same point in the heavens, which is called a sidereal day. The ordinary or solar day is in strictness of varying length, owing to the Earth's unequal motion in different parts of its orbit; but in practice a mean or average one for the whole year is adopted and called a mean solar day, and this is the unit of time in all other astronomical measurements of duration. Of these mean solar days, then, the Earth occupies 365·25636 (equal to $365^d\ 6^h\ 9^m\ 9^s$) in revolving round the Sun. But as the conveniences of life lead us to take for a day not the period of time in which the Earth rotates on its axis, so do they compel us to adopt for one year not the exact period of time in which the Earth revolves in its orbit. For what makes the observance of the

year necessary to us is the change produced by the variations in the seasons; and, in consequence of a slow gyratory movement in the Earth's axis (occupying about 25,300 years to complete a whole round), which goes under the name of the precession of the equinoxes, from the effect it produces upon the equinoctial points, the tropical year, in which all the changes of the seasons are run through, is somewhat shorter than the sidereal year, or the actual duration of the Earth's revolution round the Sun. The length in fact of the tropical year is $365^{d}\cdot24220$, or $365^{d}\ 5^{h}\ 48^{m}\ 46^{s}$. It would be so extremely awkward to make a year consist of a number of days and a fraction of a day that the difficulty is got over by adopting in the calendar **two** years: one called a common year, which consists of 365 days, and an occasional one called a bissextile or leap year, which consists of 366 days. By the old Julian reckoning, which erroneously supposed the year to contain 365¼ days exactly, this leap year was interposed every fourth year. But by the Gregorian reckoning, introduced into England in 1752, a leap-year is dropped at the end of each century, except at the end of each fourth century (*e.g.* 1900 will not be a leap-year, but 2000 will). This is equivalent to considering the year to consist of 365·24250 days, differing by only 0·00030 days, or about 26^{s}, from its true value, 365·24220 days. This small difference will not by accumulation amount to an entire day for more than 3000 years.

II. THE MOON.

In its annual journey round the Sun, the Earth is accompanied by a smaller planet called the Moon, the movement of which relatively to the Earth being in the nature of a motion in an elliptic orbit round the latter, it is considered as a satellite or secondary planet to it. The Moon, then, being by far our nearest neighbour amongst the heavenly bodies, of course much more has been learnt about her than about the others. Selenography in fact, or the knowledge and description of the surface of the Moon, has become of recent years almost a science of itself. The great work of Beer and Mädler upon it was published in the year 1837; that of Mr. Neison in 1876. But, as before remarked, we do not propose to enter in the smallest degree upon this and kindred topics. By reason of the Moon's close proximity to us, too, as compared with those of other heavenly bodies, an exact knowledge of her apparent motion amongst the stars is of the greatest practical use in navigation, for enabling the mariner to find his longitude at sea. The difficulty of this problem, which has exercised the labours of many distinguished mathematicians, arises from the perturbations to which the Moon's elliptic motion round the Earth is subjected through the gravitating action of the Sun and even of some of the planets. By reason indeed of the much greater mass of the Sun, he exerts a more powerful attractive force upon the Moon than the Earth does, although the latter is so much nearer. Exception, therefore, has been taken to calling the

Moon our satellite; and she is certainly not so quite in the sense that the satellites of Jupiter and Saturn are of those planets. Still, as we have said, her motion, relatively to the Earth, is a motion round it; she is connected with our planet by an indissoluble tie, and, from her great benefit to us, will always be called **our** satellite, exciting our gratitude and commanding our attention.

The actual duration of the Moon's orbital motion round the Earth is $27^d\ 7^h\ 43^m\ 11^s{\cdot}5$; but here again the convenience of life compels us to regard as a lunar month or lunation, not this, the sidereal time of her revolution, but the period in which she revolves from nearly being in the same direction as the Sun to the same again. This, which is sometimes called a synodic revolution, amounts to $29^d\ 12^h\ 44^m\ 2^s{\cdot}7$; upon it of course depends the Moon's phases as presented to the Earth, her light being reflected solar light. She also receives solar light reflected from the Earth; and at certain times, when the illuminated part of the Earth turned towards her is the greatest (*i. e.*, near our **New** Moon), this is sufficiently strong to be reflected back again, enabling us to see the whole surface of the Moon, as at Full Moon, only very faint. This is popularly called "the old Moon in the young Moon's arms."

Another consequence of the Moon's comparatively great proximity is that her distance and size can be determined much more accurately than those of any other heavenly body. Her distance varies in different parts of her orbit from 221,600 to 253,000 miles; the mean being a little more than 237,300, resulting from a mean horizontal parallax of $57'\ 2''$. The eccentricity of the Moon's orbit is about 0·0549; the value of its

mean inclination to the ecliptic, or earth's orbit, about 5° 8′ 40″; but the latter varies between 5° 0′ and 5° 17′.

The diameter of the Moon is about 2160 miles, or somewhat less than two-sevenths that of the Earth; so that her volume is about one-fiftieth that of the Earth. But her density being little more than half that of our own globe, her mass amounts to only about one-eightieth that of the Earth.

The Moon rotates on her axis very much more slowly than our Earth does. In fact the duration of her rotation is exactly the same as that of her revolution round the Earth. The consequence is that we always see precisely the same face of the Moon; the whole of one-half of her surface being always concealed from us, excepting such small portions of it near the visible half which come into view from librations (as they are called) produced by her varying velocity of orbital motion and the inclination of her orbit.

III. THE SUN.

Precluded by our scheme from touching on the subject of solar physics, we have little to say about the Sun excepting as the centre and ruler of the planetary system. A volume many times larger than this might be written upon the different determinations of that difficult and important problem,—the Sun's parallax and distance. Difficult on account of the Sun's great distance compared with the Earth's diameter, rendering the triangle, by the solution of which only it can be found, an extremely ill-conditioned one,

and a small error in the measured parallax producing a large error in the resulting distance. Important, because on this depends our knowledge of all other magnitudes in the solar system (besides being the unit of any approximate measures we may be able to take beyond it). For by Kepler's third law, the proportions of the distances of all the bodies moving round the Sun are known exactly from their periodic times of revolution, so that if the Earth's distance be known, those of all the planets can be deduced by a very simple piece of arithmetic. We do not intend here to treat of the history of this, but merely to give what may now be considered the value nearest to the true one. From the time of Flamsteed, it has been known that the Sun's parallax is so small as not to exceed $10''$. Halley pointed out the advantage that might be gained by observing the transits of Venus on those rare occasions when she passes at inferior conjunction over the Sun's disc. The transits of 1761 and 1769 were accordingly observed by a large number of parties sent to different parts of the world for the purpose. But the solution of the problem in this manner is encompassed by practical difficulties. Many results were obtained by a calculation from the observations of the transits of those years; but for a long time it was agreed amongst astronomers that the value obtained by Encke, which amounted to $8''\cdot571$, was the best. More recently many considerations have forced them to believe that this is somewhat too small. Determinations made by observing Mars (which when in opposition approaches us sometimes almost as nearly as Venus when in inferior conjunction), and by other methods, have shown that the Sun's parallax is

probably greater by at least $0''\cdot 3$ than Encke's value for it. Moreover, it was shown that the latter proceeded from an erroneous interpretation of some of the observations. Rightly explained, they also gave a value considerably larger than his; and the observations of the more recent transits in 1874 and 1882 likewise (although the method is somewhat discredited as compared with other methods on account of its practical difficulties) prove to be most consistent with a value not very different from $8''\cdot 8$. A full consideration of the results obtained by all the methods leads us to the conclusion that the actual most probable value of the Sun's parallax is $8''\cdot 78$; a value obtained too by Mr. Gill from his careful observations of Mars in Ascension Island during that planet's favourable opposition in 1877. This value of the parallax gives for the Sun's distance very nearly 93,000,000 miles. It is not likely that this distance will ever be known within a quarter of a million of miles. But it must be noted, that in consequence of the eccentricity of the Earth's orbit, the Sun's actual distance varies between a million and a half miles less, and a million and a half miles more than this; being least when the Earth is at that end of the major axis of its orbit which is nearest the focus occupied by the Sun, and greatest when the Earth is at the other end of that axis, these two points being called respectively the perihelion and the aphelion of the Earth's orbit.

Accepting, then, 93,000,000 miles as the Sun's mean distance from us, it is easy to find, by observing his apparent diameter, that his real diameter is about 865,000 miles. This is about 108 times as great as the Earth's, and would make the Sun's volume able to

contain the Earth's about 1,300,000 times over. But it has been found by physical astronomers that the Sun's mass is only about 330,400 times as great as that of the Earth. Consequently his density must amount to only about 0·25 that of the Earth.

The shape of the Sun would seem to be that of a perfect sphere. As soon as he was observed through a telescope it was seen that his surface was usually diversified by a number of black spots of varying dimensions and appearances. The motions of these made it evident that the sun is endued with a stately rotation on his axis. These motions are such as would carry a spot from first appearing on the Sun's disc to appearing there again (if it was persistent enough to do so) in about 27 days; hence, taking into account the simultaneous motion of the Earth in its orbit round the Sun, it was inferred that the Sun turns on his axis in about $25^d\ 7^h$. It should be stated, however, that more recent observations have shown that the spots nearer the Sun's equator move somewhat more rapidly than those farther from it (all are confined within a region of about 30° on each side of the equator); so that we cannot fix the time of the Sun's rotation on its axis more definitely than that it varies from 25 to 26½ days.

One other point concerning the spots may be mentioned here; we mean their periodicity. This was first noticed by Schwabe of Dessau about sixty years ago, and from the attention which it has attracted since, the period, so far as it is constant, is pretty accurately determined to be a little more than eleven years. The last epoch of maximum of abundance and frequency was in 1883; and as the diminution is

generally less rapid than the increase, we may expect another minimum about 1889, and another maximum about 1893.

IV. THE PLANETS GENERALLY.

ALL the planets revolve in the same direction round the Sun at very various distances. These distances, however, are all connected with their respective periods of revolution by Kepler's third law, which Newton proved to be a necessary consequence of their being attracted to him by a force, identical in actual intensity, but diminishing in its effects, in the same proportion in which the square of the distance increases. Kepler's first law is that all the planets revolve round the Sun in elliptic orbits; his second, that in doing so their radii vectores (or the lines connecting them as they move with the Sun) sweep out in their orbits areas which are directly proportionate to the times of sweeping. These laws Newton also showed necessarily to result from the planets being each attracted to the Sun by a force acting according to the inverse square of the distance.

The planets may be divided into four groups. (1.) Four of moderate size nearest the Sun, of which four the Earth ranks third in order of distance from him. (2.) A large number, of which 237 members are now known, of very small planets revolving between the orbits of Mars and Jupiter. (3.) Four very large planets moving in orbits exterior to all these, the outermost being Neptune, whose mean distance from the Sun is about thirty times that of the Earth.

It has been surmised, but never proved, that a planet revolves round the Sun nearer him than Mercury. Whether any exist further from him than Neptune, it is impossible at present to say. Uranus was not discovered until 1781; Neptune not till 1846, though both had been seen before their discovery, when they were supposed to be fixed stars. Until little more than a hundred years ago, therefore, there were supposed to be only five planets besides our Earth.

We shall conclude this chapter with the following Table of the Names, Symbols, and the most important orbital elements of the eight principal planets, forming the first and third of the above groups. Of the small planets composing the second group, we shall merely give in the proper place a list of the names, discoverers, and dates of discovery.

Planet.	Symbol.	Period in Days.	Comparative Mean Distance from the Sun	Eccentricity of Orbit.	Inclination of Orbit to Ecliptic. ° ′ ″
Mercury	☿	87·969	0·38710	0·20560	7 0 8
Venus	♀	224·701	0·72333	0·00684	3 23 35
Earth	⊕	365·256	1·00000	0·01677	0 0 0
Mars	♂	686·980	1·52369	0·09326	1 51 2
Jupiter	♃	4332·588	5·20280	0·04825	1 18 41
Saturn	♄	10759·236	9·53886	0·05607	2 29 40
Uranus	♅	30688·390	19·18338	0·04636	0 46 21
Neptune	♆	60181·113	30·05437	0·00899	1 46 59

A comparison of the numbers in the third and fourth columns of the above table will show that Kepler's third law is maintained throughout. That law is that the squares of the periodic times of any two planets moving round the Sun are in the same proportion as the cubes of their mean distances from him.

V. THE INFERIOR PLANETS FORMING THE FIRST GROUP.

As the third member of this group is our own Earth, treated of in the first chapter, it remains to give a few particulars about Mercury and Venus, the two planets whose orbits are inferior to that of the Earth, and which are sometimes called **Inferior Planets**, and about Mars, our nearest neighbour outwards, the mean distance of which from the Sun is about half as great again as ours. As will be seen by the Table at the end of the last chapter, the eccentricity of his orbit is the greatest amongst the principal planets with the sole exception of Mercury.

Mercury and Venus, from being nearer the Sun than ourselves, can never come into apparent opposition to the Sun as seen from the Earth. But they may come into inferior conjunction with the Sun; and if at that time one of them is near the node of its orbit, where it crosses the plane of the Earth's, the planet will be seen to pass like a round black spot across the Sun, making what is called a transit over his disc. The first time Mercury was ever seen on the Sun's disc was by Gassendi at Paris on Nov. 7, 1631. One which occurred on the same day in the year 1677 was well observed by Halley at St. Helena, and this led him to suggest the observation of a transit of Venus when it should occur as the best means of obtaining the distance of the Sun. Venus had already been seen on the Sun by two young Englishmen in Lancashire, Horrox and Crabtree, in the year 1639. No other transit would take place until 1761; it, as

well as the following transit in 1769, was (as we have already remarked) extensively observed, and so have since been those of 1874 and 1882. The next pair of transits of Venus will occur in 2004 and 2012. Transits of Mercury take place much more frequently than those of Venus. The last occurred in 1881; two more will take place before the end of this century, viz. in 1891 and 1894.

Mercury can only be seen with the naked eye when near greatest elongation from the Sun (which seldom exceeds 18°), a little before sunrise or after sunset, as the case may be. He is too near the Sun to allow us to make any very accurate observations of his shape, or see anything very distinctly on his surface. His diameter is about 2990 miles, and if his figure be elliptical, it is probably very slightly so. It has been thought that markings on his surface indicate a period of rotation on his axis about equal in length to that of our Earth; but this has not been confirmed, and the conclusion therefore remains doubtful. The mass of Mercury is about one-twelfth that of the Earth, and his density must therefore be a little greater than that of our planet.

Venus moves in an orbit more nearly circular than that of any other of the principal planets. The inclination of her orbit to the Earth's is greater than that of any other except Mercury. Her greatest elongation from the Sun amounts to about 45°, so that she may sometimes be seen for a very considerable part of the night before sunrise or after sunset. In very ancient times, she was called when seen in the morning, Phosphorus, and when seen in the evening, Hesperus. Her phases were first noticed by Galileo in 1610.

The diameter of Venus is about 7660 miles, only a little less than that of the Earth. Her mass is smaller than that of our planet, sufficiently so to make us conclude that her density as well as her size must be somewhat smaller. There are strong indications of the existence of a very considerable atmosphere on Venus; and also that this is so loaded with dense clouds as to render it impossible to observe any permanent markings on her surface, or determine the time of her axial rotation. Some observations of this kind have indeed, as in the case of Mercury, been published, tending to the conclusion that Venus rotates in about $23^h\ 21^m$; but this conclusion is regarded by astronomers as very doubtful. As Prof. Newcomb remarks, "the circumstance that the deduced times of rotation in the cases both of Mercury and Venus differ so little from that of the Earth is somewhat suspicious, because if the appearance were due to any optical illusion, or imperfection of the telescope, it might repeat itself several days in succession, and thus give rise to the belief that the time of rotation was nearly one day." The axial rotations, then, of these two planets cannot be considered as established, though we cannot doubt that a rotation of some sort exists on both.

Mars is a considerably smaller planet than the Earth, his diameter being only about 4200 miles. His density is less than that of Venus, and only about three-quarters that of the Earth, the mass of which is about nine times that of Mars.

The disc of this planet is well seen with our telescopes, and many maps have been drawn of the surface, which exhibits in many respects a striking

analogy with the surface of our Earth. The duration of its axial rotation is now very accurately known, and amounts to $24^h\ 37^m\ 23^s$. The axis is inclined to the orbit at an angle of about 63°, somewhat less than in the case of the Earth, so that the inclination of his equator to the plane of motion is greater by about $3\frac{1}{2}°$ than on our planet. Mars appears to be surrounded by an atmosphere of considerable density.

In the year 1877, it was discovered by Prof. Asaph Hall of Washington, that this planet is attended by two very small satellites, to which he afterwards gave the names of Phobos and Deimos respectively. The inner of these (Phobos) is the brightest and probably somewhat the largest of the two; but it is supposed that neither of them exceeds ten miles in diameter. The period of the inner satellite round Mars is only about $7^h\ 39^m$; that of the outer about $30^h\ 18^m$. The distance of Phobos from the centre of Mars is only about 6000 miles, so that its distance from the nearest point of the surface of the planet must be less than 4000 miles, or than the radius of the Earth. Deimos is about two and a half times as far from Mars as Phobos, its distance from the planet being approximately 15,000 miles.

VI. THE SMALL PLANETS FORMING THE SECOND GROUP.

Of this large and constantly-increasing group, not much can ever be known excepting their motions. Even the largest is supposed not to exceed 200 miles in diameter. Early in the present century the first

four members of it were discovered; then no more until 1845, since which time the course of discovery has been continuous, no year having elapsed without the discovery of at least one, and in some many new ones have been found. The orbits of several are very eccentric, and the inclinations of the orbits of some to the ecliptic greatly exceed those of any of the principal planets. Advantage has been taken of the positions of a few when near opposition to use observations of them in determining the Sun's parallax and distance. We append a Table of their names, discoverers, and dates of discovery, including all that have been detected up to the end of June, 1884.

It will be noticed that Melete is numbered 56 although discovered in 1857, because it was long supposed that the observations of it were in fact observations of Daphne, No. 41, and when the mistake was detected in 1859, and Melete was recognized as another new planet, it was impossible to disturb the numbers of several which had been discovered in 1857 and 1858. Juewa, No. 139, was discovered in China whilst Prof. Watson was there on an expedition to observe the transit of Venus in 1874.

LIST OF SMALL PLANETS.

No.	Name.	Date of Discovery.	Discoverer.	Place of Discovery.
1	Ceres	1801, Jan. 1	Piazzi	Palermo
2	Pallas	1802, Mar. 28	Olbers	Bremen
3	Juno	1804, Sept. 1	Harding	Lilienthal
4	Vesta	1807, Mar. 29	Olbers	Bremen
5	Astræa	1845, Dec. 8	Hencke	Driesen
6	Hebe	1847, July 1	Hencke	Driesen
7	Iris	1847, Aug. 13	Hind	London

No.	Name.	Date of Discovery.	Discoverer.	Place of Discovery.
8	Flora	1847, Oct. 18	Hind	London
9	Metis	1848, April 25	Graham	Markree
10	Hygiea	1849, April 12	De Gasparis	Naples
11	Parthenope	1850, May 11	De Gasparis	Naples
12	Victoria	1850, Sept. 13	Hind	London
13	Egeria	1850, Nov. 2	De Gasparis	Naples
14	Irene	1851, May 19	Hind	London
15	Eunomia	1851, July 29	De Gasparis	Naples
16	Psyche	1852, Mar. 17	De Gasparis	Naples
17	Thetis	1852, April 17	Luther	Bilk
18	Melpomene	1852, June 24	Hind	London
19	Fortuna	1852, Aug. 22	Hind	London
20	Massilia	1852, Sept. 19	De Gasparis	Naples
21	Lutetia	1852, Nov. 15	Goldschmidt	Paris
22	Calliope	1852, Nov. 16	Hind	London
23	Thalia	1852, Dec. 15	Hind	London
24	Themis	1853, April 5	De Gasparis	Naples
25	Phocæa	1853, April 6	Chacornac	Marseilles
26	Proserpine	1853, May 5	Luther	Bilk
27	Euterpe	1853, Nov. 8	Hind	London
28	Bellona	1854, Mar. 1	Luther	Bilk
29	Amphitrite	1854, Mar. 1	Marth	London
30	Urania	1854, July 22	Hind	London
31	Euphrosyne	1854, Sept. 1	Ferguson	Washington
32	Pomona	1854, Oct. 26	Goldschmidt	Paris
33	Polyhymnia	1854, Oct. 28	Chacornac	Paris
34	Circe	1855, April 6	Chacornac	Paris
35	Leucothea	1855, April 19	Luther	Bilk
36	Atalanta	1855, Oct. 5	Goldschmidt	Paris
37	Fides	1855, Oct. 5	Luther	Bilk
38	Leda	1856, Jan. 12	Chacornac	Paris
39	Lætitia	1856, Feb. 8	Chacornac	Paris
40	Harmonia	1856, Mar. 31	Goldschmidt	Paris
41	Daphne	1856, May 22	Goldschmidt	Paris
42	Isis	1856, May 23	Pogson	Oxford
43	Ariadne	1857, April 15	Pogson	Oxford
44	Nysa	1857, May 27	Goldschmidt	Paris
45	Eugenia	1857, June 28	Goldschmidt	Paris
46	Hestia	1857, Aug. 16	Pogson	Oxford
47	Aglaia	1857, Sept. 15	Luther	Bilk
48	Doris	1857, Sept. 19	Goldschmidt	Paris
49	Pales	1857, Sept. 19	Goldschmidt	Paris
50	Virginia	1857, Oct. 4	Ferguson	Washington
51	Nemausa	1858, Jan. 22	Laurent	Nismes

No.	Name.	Date of Discovery.	Discoverer.	Place of Discovery.
52	Europa	1858, Feb. 6	Goldschmidt	Paris
53	Calypso	1858, April 4	Luther	Bilk
54	Alexandra	1858, Sept. 10	Goldschmidt	Paris
55	Pandora	1858, Sept. 10	Searle	Albany, U.S.
56	Melete	1857, Sept. 9	Goldschmidt	Paris
57	Mnemosyne	1859, Sept. 22	Luther	Bilk
58	Concordia	1860, Mar. 24	Luther	Bilk
59	Olympia	1860, Sept. 12	Chacornac	Paris
60	Echo	1860, Sept. 15	Ferguson	Washington
61	Danaë	1860, Sept. 19	Goldschmidt	Paris
62	Erato	1860, Oct. 10	Förster	Berlin
63	Ausonia	1861, Feb. 10	De Gasparis	Naples
64	Angelina	1861, Mar. 4	Tempel	Marseilles
65	Cybele	1861, Mar. 8	Tempel	Marseilles
66	Maia	1861, April 9	Tuttle	Cambridge, U.S.
67	Asia	1861, April 17	Pogson	Madras
68	Leto	1861, April 29	Luther	Bilk
69	Hesperia	1861, April 29	Schiaparelli	Milan
70	Panopæa	1861, May 5	Goldschmidt	Paris
71	Niobe	1861, Aug. 13	Luther	Bilk
72	Feronia	1861, May 29	Peters	Clinton, U.S.
73	Clytie	1862, April 7	Tuttle	Cambridge, U.S.
74	Galate a	1862, Aug. 29	Tempel	Marseilles
75	Eurydice	1862, Sept. 22	Peters	Clinton, U.S.
76	Freia	1862, Oct. 21	D'Arrest	Copenhagen
77	Frigga	1862, Nov. 12	Peters	Clinton, U.S.
78	Diana	1863, Mar. 15	Luther	Bilk
79	Eurynome	1863, Sept. 14	Watson	Ann Arbor, U.S.
80	Sappho	1864, May 3	Pogson	Madras
81	Terpsichore	1864, Sept. 30	Tempel	Marseilles
82	Alcmene	1864, Nov. 27	Luther	Bilk
83	Beatrix	1865, April 26	De Gasparis	Naples
84	Clio	1865, Aug. 25	Luther	Bilk
85	Io	1865, Sept. 19	Peters	Clinton, U.S.
86	Semele	1866, Jan. 6	Tietjen	Berlin
87	Sylvia	1866, May 16	Pogson	Madras
88	Thisbe	1866, June 15	Peters	Clinton, U.S.
89	Julia	1866, Aug. 6	Stephan	Marseilles
90	Antiope	1866, Oct. 1	Luther	Bilk
91	Ægina	1866, Nov. 4	Stephan	Marseilles
92	Undina	1867, July 7	Peters	Clinton, U.S.
93	Minerva	1867, Aug. 24	Watson	Ann Arbor, U.S.
94	Aurora	1867. Sept. 26	Watson	Ann Arbor, U.S.
95	Arethusa	1867, Nov. 23	Luther	Bilk

No.	Name.	Date of Discovery.	Discoverer.	Place of Discovery.
96	Ægle	1868, Feb. 17	Coggia	Marseilles
97	Clotho	1868, Feb. 17	Tempel	Marseilles
98	Ianthe	1868, April 18	Peters	Clinton, U.S.
99	Dike	1868, May 29	Borrelly	Marseilles
100	Hecate	1868, July 11	Watson	Ann Arbor, U.S.
101	Helena	1868, Aug. 16	Watson	Ann Arbor, U.S.
102	Miriam	1868, Aug. 22	Peters	Clinton, U.S.
103	Hera	1868, Sept. 7	Watson	Ann Arbor, U.S.
104	Clymene	1868, Sept. 13	Watson	Ann Arbor, U.S.
105	Artemis	1868, Sept. 16	Watson	Ann Arbor, U.S.
106	Dione	1868, Oct. 10	Watson	Ann Arbor, U.S.
107	Camilla	1868, Nov. 17	Pogson	Madras
108	Hecuba	1869, April 2	Luther	Bilk
109	Felicitas	1869, Oct. 9	Peters	Clinton, U.S.
110	Lydia	1870, April 19	Borrelly	Marseilles
111	Ate	1870, Aug. 14	Peters	Clinton, U.S.
112	Iphigenia	1870, Sept. 19	Peters	Clinton, U.S.
113	Amalthea	1871, Mar. 12	Luther	Bilk
114	Cassandra	1871, July 24	Peters	Clinton, U.S.
115	Thyra	1871, Aug. 6	Watson	Ann Arbor, U.S.
116	Sirona	1871, Sept. 8	Peters	Clinton, U.S.
117	Lomia	1871, Sept. 12	Borrelly	Marseilles
118	Peitho	1872, Mar. 15	Luther	Bilk
119	Althæa	1872, April 3	Watson	Ann Arbor, U.S.
120	Lachesis	1872, April 10	Borrelly	Marseilles
121	Hermione	1872, May 12	Watson	Ann Arbor, U.S.
122	Gerda	1872, July 31	Peters	Clinton, U.S.
123	Brunhilda	1872, July 31	Peters	Clinton, U.S.
124	Alcestis	1872, Aug. 23	Peters	Clinton, U.S.
125	Liberatrix	1872, Sept. 11	Prosper Henry	Paris
126	Velleda	1872, Nov. 5	Paul Henry	Paris
127	Johanna	1872, Nov. 5	Prosper Henry	Paris
128	Nemesis	1872, Nov. 25	Watson	Ann Arbor, U.S.
129	Antigone	1873, Feb. 5	Peters	Clinton, U.S.
130	Electra	1873, Feb. 17	Peters	Clinton, U.S.
131	Vala	1873, May 24	Peters	Clinton, U.S.
132	Æthra	1873, June 13	Watson	Ann Arbor, U.S.
133	Cyrene	1873, Aug. 16	Watson	Ann Arbor, U.S.
134	Sophrosyne	1873, Sept. 27	Luther	Bilk
135	Hertha	1874, Feb. 18	Peters	Clinton, U.S.
136	Austria	1874, Mar. 18	Palisa	Pola
137	Melibæa	1874, April 21	Palisa	Pola

No.	Name.	Date of Discovery.	Discoverer.	Place of Discovery.
138	Tolosa	1874, May 19	Perrotin	Toulouse
139	Juewa	1874, Oct. 10	Watson	Pekin
140	Siwa	1874, Oct. 13	Palisa	Pola
141	Lumen	1875, Jan. 13	Paul Henry	Paris
142	Polana	1875, Jan. 28	Palisa	Pola
143	Adria	1875, Feb. 23	Palisa	Pola
144	Vibilia	1875, June 3	Peters	Clinton, U.S.
145	Adeona	1875, June 3	Peters	Clinton, U.S.
146	Lucina	1875, June 8	Borrelly	Marseilles
147	Protogeneia	1875, July 10	Schulhof	Vienna
148	Gallia	1875, Aug. 7	Prosper Henry	Paris
149	Medusa	1875, Sept. 21	Perrotin	Toulouse
150	Nuwa	1875, Oct. 18	Watson	Ann Arbor, U.S.
151	Abundantia	1875, Nov. 1	Palisa	Pola
152	Atala	1875, Nov. 2	Paul Henry	Paris
153	Hilda	1875, Nov. 2	Palisa	Pola
154	Bertha	1875, Nov. 4	Prosper Henry	Paris
155	Scylla	1875, Nov. 8	Palisa	Pola
156	Xanthippe	1875, Nov. 22	Palisa	Pola
157	Dejanira	1875, Dec. 1	Borrelly	Marseilles
158	Koronis	1876, Jan. 4	Knorre	Berlin
159	Æmilia	1876, Jan. 26	Paul Henry	Paris
160	Una	1876, Feb. 20	Peters	Clinton, U.S.
161	Athor	1876, April 18	Watson	Ann Arbor, U.S.
162	Laurentia	1876, April 21	Prosper Henry	Paris
163	Erigone	1876, April 26	Perrotin	Toulouse
164	Eva	1876, July 12	Paul Henry	Paris
165	Loreley	1876, Aug. 10	Peters	Clinton, U.S.
166	Rhodope	1876, Aug. 17	Peters	Clinton, U.S.
167	Urda	1876, Aug. 29	Peters	Clinton, U.S.
168	Sibylla	1876, Sept. 27	Watson	Ann Arbor, U.S.
169	Zelia	1876, Sept. 28	Prosper Henry	Paris
170	Maria or Myrrha	1877, Jan. 10	Perrotin	Toulouse
171	Ophelia	1877, Jan. 13	Borrelly	Marseilles
172	Baucis	1877, Feb. 5	Borrelly	Marseilles
173	Ino	1877, Aug. 2	Borrelly	Marseilles
174	Phædra	1877, Sept. 3	Watson	Ann Arbor, U.S.
175	Andromache	1877, Oct. 1	Watson	Ann Arbor, U.S.

No.	Name.	Date of Discovery.	Discoverer.	Place of Discovery.
176	Idunna	1877, Oct. 14	Peters	Clinton, U.S.
177	Irma	1877, Nov. 5	Paul Henry	Paris
178	Belisana	1877, Nov. 6	Palisa	Pola
179	Clytem-nestra	1877, Nov. 12	Watson	Ann Arbor, U.S.
180	Garumna	1878, Jan. 29	Perrotin	Toulouse
181	Eucharis	1878, Feb. 2	Cottenot	Marseilles
182	Elsa	1878, Feb. 7	Palisa	Pola
183	Istria	1878, Feb. 8	Palisa	Pola
184	Deiopeia	1878, Feb. 28	Palisa	Pola
185	Eunike	1878, Mar. 1	Peters	Clinton, U.S.
186	Celuta	1878, April 6	Prosper Henry	Paris
187	Lamberta	1878, April 11	Coggia	Marseilles
188	Menippe	1878, June 18	Peters	Clinton, U.S.
189	Phthia	1878, Sept. 9	Peters	Clinton, U.S.
190	Ismene	1878, Sept. 22	Peters	Clinton, U.S.
191	Kolga	1878, Sept. 30	Peters	Clinton, U.S.
192	Nausikaa	1879, Feb. 17	Palisa	Pola
193	Ambrosia	1879, Feb. 28	Coggia	Marseilles
194	Prokne	1879, Mar. 21	Peters	Clinton, U.S.
195	Eurykleia	1879, April 22	Palisa	Pola
196	Philomela	1879, May 14	Peters	Clinton, U.S.
197	Arete	1879, May 21	Palisa	Pola
198	Ampella	1879, June 13	Borrelly	Marseilles
199	Byblis	1879, July 9	Peters	Clinton, U.S.
200	Dynamene	1879, July 27	Peters	Clinton, U.S.
201	Penelope	1879, Aug. 7	Palisa	Pola
202	Chryseis	1879, Sept. 11	Peters	Clinton, U.S.
203	Pompeia	1879, Sept. 25	Peters	Clinton, U.S.
204	Callisto	1879, Oct. 8	Palisa	Pola
205	Martha	1879, Oct. 13	Palisa	Pola
206	Hersilia	1879, Oct. 15	Peters	Clinton, U.S.
207	Hedda	1879, Oct. 17	Palisa	Pola
208	Lacrimosa	1879, Oct. 21	Palisa	Pola
209	Dido	1879, Oct. 22	Peters	Clinton, U.S.
210	Isabella	1879, Nov. 12	Palisa	Pola
211	Isolda	1879, Dec. 10	Palisa	Pola
212	Medea	1880, Feb. 6	Palisa	Pola
213	Lilæa	1880, Feb. 16	Peters	Clinton, U.S.
214	Aschera	1880, Mar. 1	Palisa	Pola
215	Œnone	1880, April 7	Knorre	Berlin
216	Cleopatra	1880, April 10	Palisa	Pola
217	Eudora	1880, Aug. 30	Coggia	Marseilles

No.	Name.	Date of Discovery.	Discoverer.	Place of Discovery.
218	Bianca	1880, Sept. 4	Palisa	Pola
219	Thusnelda	1880, Sept. 30	Palisa	Pola
220	Stephania	1881, May 19	Palisa	Vienna
221	Eos	1882, Jan. 18	Palisa	Vienna
222	Lucia	1882, Feb. 9	Palisa	Vienna
223	Rosa	1882, Mar. 9	Palisa	Vienna
224	Oceana	1882, Mar. 30	Palisa	Vienna
225	Henrietta	1882, April 19	Palisa	Vienna
226	Weringia	1882, July 19	Palisa	Vienna
227	Philosophia	1882, Aug. 12	Paul Henry	Paris
228	Agatha	1882, Aug. 19	Palisa	Vienna
229	Adelinda	1882, Aug. 22	Palisa	Vienna
230	Athamantis	1882, Sept. 3	De Ball	Bothkamp
231	Vindobona	1882, Sept. 10	Palisa	Vienna
232	Russia	1883, Jan. 31	Palisa	Vienna
233	Asterope	1883, May 11	Borrelly	Marseilles
234	Barbara	1883, Aug. 12	Peters	Clinton, U.S.
235	Carolina	1883, Nov. 28	Palisa	Vienna
236	Honoria	1884, April 26	Palisa	Vienna
237	Cœlestina	1884, June 27	Palisa	Vienna

In each of the years 1848, 1849, 1859, and 1881 only one small planet was discovered. No less than twenty were discovered in 1879, the year most abundant in this respect. The most successful discoverers have been Prof. C. H. F. Peters of the Litchfield Observatory, Hamilton College, Clinton, N.Y., and Dr. J. Palisa, formerly Director of the Observatory at Pola, but now attached to the Imperial Observatory at Vienna, each of whom has discovered no less than forty-two of these bodies. The first of those found by the former astronomer was Feronia, No. 72, discovered on May 29, 1861, but not recognized as a new planet until the autumn of that year, when this was shown to be so by the calculations of Prof. Safford, after the discovery of Niobe, so that, like Melete, it does not bear the number corresponding to the date of its discovery.

VII. THE EXTERIOR PLANETS, FORMING THE THIRD GROUP.

We have said that all the planets which move in orbits exterior to those of the small planets, are much larger than those moving in orbits interior to theirs. The first of these, composing our third group, is the largest planet of all, Jupiter, sometimes called the giant planet, the bulk of which is about 1300 times as great as that of our globe, its diameter being about 86,000 miles. But its mass being only about 300 times that of the Earth, its density must be less than a quarter that of the latter. The proportion of its mass to that of the Sun is very nearly that of 1 to 1049.

The ellipticity of Jupiter's figure is considerable, and attracts attention the moment it is seen with a moderately large telescope; the compression in fact (or fraction representing the difference between the polar and equatorial diameters divided by the latter) amounts, according to the best measures which have been made of it, to about $\frac{1}{17}$ (whilst that of the Earth is only $\frac{1}{312}$, and that of Mars probably does not exceed $\frac{1}{100}$). The planet is surrounded by a thick atmosphere, in which are dense masses of cloud. The belts and spots on the surface are interesting objects of study, but it does not fall within our plan to speak of them in detail here. A remarkable red spot has attracted very special attention during the last few years, but has now disappeared, or nearly so. The motions of the spots have furnished means of obtaining the time of Jupiter's axial rotation with considerable accuracy. It is more

rapid than that of any other planet of which the rotation is known with accuracy, and certainly does not differ much from $9^h\ 55^m$. The axis being nearly perpendicular to the plane of the orbit, the equator makes but a very small angle with the latter.

As soon as telescopes were directed to Jupiter, it was seen that he was accompanied by four attendant moons or satellites. The claim of Galileo to be the first discoverer of these has been contested, but it is generally allowed with injustice. He first saw them on January 7, 1610; and an account of his subsequent observations proving them to be satellites, is contained in his 'Sidereus Nuncius,' parts of which have been recently translated by Mr. Carlos. Simon Marius (or rather Mayr) claimed to be the discoverer, but this claim (to which we have just alluded) is considered to have been disproved. Mayr proposed a name for each satellite, but his proposed names have not been accepted, lest the acceptance should seem to imply recognition of his claim. Galileo named them jointly the Medicean stars, a designation which has been dropped by general consent, but he made no attempt to name them individually. Nor has any inconvenience ever arisen from the want of names; for as they were all discovered at the same time, and were called the First, Second, Third, and Fourth Satellite respectively, reckoning according to their distance from Jupiter outwards, this nomenclature has been found quite sufficient. Their distances from Jupiter, periods of revolution round him, and approximate diameters are as follows:—

Satellite.	Distance from Jupiter.	Period.	Diameter.
	Miles.	d. h. m.	Miles.
I.	267,000	1 18 29	2400
II.	425,000	3 13 18	2100
III.	678,000	7 4 0	3400
IV.	1,193,000	16 18 5	2900

The next largest planet to Jupiter is Saturn, the diameter of which is about 72,000 miles, so that its bulk is rather more than half that of the giant planet, and would contain the Earth's about 750 times. But his density is not much more than half that of Jupiter, and the mass of the latter is equal to between three and four times that of Saturn. Indeed, the mass of Jupiter is more than double that of all the other planets put together, whilst his volume is about one and a half times as great as the aggregate of all the rest. The compression of the figure of Saturn has been determined to be the greatest of that of any planet of which the ellipticity is measurable, and to amount to as much as $\frac{1}{8}$.

Belts are to be seen on Saturn similar to those on Jupiter, but they are much fainter on account of the greater distance. Nevertheless, by their aid the axial rotation has been pretty accurately determined to be somewhat slower than that of Jupiter, its period amounting to about $10^h\ 15^m$. As in the case of Jupiter, the axis is very nearly perpendicular to the plane of the orbit.

There are now known to be eight satellites moving round Saturn, and owing to the confusion arising from the order of discovery being different from that of the distance from the planet, it became necessary to

give them names, and those proposed by Sir John Herschel have been generally accepted. Counting outwards from Saturn, these are respectively—Mimas, Enceladus, Tethys, Dione, Rhea, Titan, Hyperion, and Japetus. The largest of these is Titan; it was the first discovered, by Huygens, on March 25, 1655. John Dominic Cassini discovered Japetus in 1671, Rhea in 1672, and Tethys and Dione in 1684. No more were discovered until Sir W. Herschel found the two innermost, Mimas and Enceladus, in the autumn of 1789. Finally, Hyperion, reckoning as seventh in the order of distance, was discovered independently by Bond in America and by Lassell in England in the month of September, 1848. The following is a list of their approximate distances from Saturn, and periods of revolution round him. Of their actual sizes, only very rough estimates are possible: Titan is probably about 3200 miles in diameter, Japetus 1800, and Rhea 1200; Mimas is somewhat the largest of the four interior satellites, all which, besides Hyperion, are probably less than 1000 miles in diameter.

Name of Satellite.	Distance from Saturn.	Period.		
	Miles.	d.	h.	m.
Mimas	121,000	0	22	37
Enceladus	155,000	1	8	53
Tethys	192,000	1	21	18
Dione	246,000	2	17	41
Rhea	343,000	4	12	25
Titan	796,000	15	22	41
Hyperion	1,007,000	21	7	7
Japetus	2,314,000	79	7	53

Saturn is unique amongst the planets in the possession of a ring or rather system of concentric rings

surrounding it within the orbits of all its satellites. This ring, which has in so many ways been an enigma to astronomers, is now understood to consist in fact of an innumerable multitude of very small satellites, so arranged as to present at a distance the appearance of a thin flat ring, with several narrow divisions in its breadth. When Galileo first saw Saturn with a telescope he was astonished to see what he thought a small body adhering to it on each side, which afterwards disappeared, recalling to mind the old myth about Saturn devouring his own children. Huygens was the first to explain the real nature of the appendage and its varying appearance according to the position of Saturn with regard to the Sun and Earth, which he did in the year 1656 in the words: "Annulo cingitur tenui plano, nusquam cohærente, ad eclipticum inclinato." * In his great work on the subject he refers to the observations of William Ball in England as confirming his own. In 1675 Cassini in France showed that there was a division in the ring. The inner ring of these two is perceptibly brighter than the outer, and it appears that Campani at Rome so early as 1664 had noticed the greater brightness of the interior portion of the ring, though he failed to recognize an actual division between the two parts thus distinguished. Other smaller divisions have been noticed since, particularly one in the outer ring by Encke in 1837. But the most remarkable recent discovery in this system of rings is that of what is technically called the dusky ring, inside the two bright rings. This is due to the Bonds of Cambridge, U.S.,

* It is surrounded by a thin plane ring, nowhere adhering to it, and inclined to the ecliptic.

in 1850, though there are several indications that a shading off of the inner bright ring towards the planet had been noticed long before. Galle had in fact called special attention to it under this description in 1838. Lassell compared the dusky ring to "something like a crape veil covering a part of the sky within the inner ring;" and its transparency was afterwards noticed. Doubtless its appearance is due to the tiny satellites of which it is composed being much more scattered than those forming the bright rings. It should be mentioned that the outer diameter of the exterior ring amounts to about 166,000 miles; its inner diameter to about 146,000 miles; the outer diameter of the interior bright ring to about 143,000, and its inner diameter to about 110,000 miles. The nearest distance of the innermost satellite from the exterior ring is probably not more than 40,000 miles.

We now come to the first principal planet of which the existence was not known to the ancients. Uranus was discovered by Sir William Herschel on March 13, 1781, and at first supposed by him to be a slowly-moving comet. Its planetary character was established as soon as the nature of its orbit became approximately known; and the principal credit of showing this is due to Lexell, whose name is more generally known by its connection with the comet of 1770, which he determined to be moving in an orbit of short period, and predicted its return, but it failed to appear on account of getting close to Jupiter and his satellites, thereby undergoing a complete change in the form of its orbit.

Uranus takes more than 84 of our years to revolve round the Sun. It was seen several times before

Herschel's discovery, but always supposed to be a fixed star; the first of these observations was by Flamsteed in 1690. Its diameter is about 32,000 miles.

Some recent observations made by Prof. Schiaparelli at Milan and by Prof. C. A. Young of Princeton, New Jersey, U.S., tend to confirm results obtained by Mädler at Dorpat about forty years ago (in 1842-3), that this planet has observable markings on its surface, and that these indicate that it has a considerable degree of ellipticity, greater than that of any other planet except Saturn (Prof. Young makes it amount to $\frac{1}{14}$, Prof. Schiaparelli to $\frac{1}{11}$), and also that it has, like Jupiter and Saturn, a rapid rotation, performed in a period of about ten hours.

The density of Uranus is a little less than that of Jupiter, and is about 0·23 that of the Earth; its mass is rather less than the twentieth part of that of the giant planet.

About six years after its discovery, or early in 1787, Sir W. Herschel discovered two satellites revolving round Uranus; he afterwards thought he had discovered four more, but the existence of these has not been confirmed. Of course it requires a very powerful telescope to perceive reflected light at so great a distance; and the searches made must be allowed to have proved that no such bodies as these four latter supposed satellites existed, but that some small fixed stars near the planet were taken for such. But two other satellites, additional to Herschel's first two, were discovered by Mr. Lassell towards the end of the year 1851; and on removing his telescope temporarily to Malta the following year in order to profit by its transparent sky, he succeeded in determining the

periods of these with considerable accuracy. These two, which are interior to Herschel's two, were named Ariel and Umbriel; whilst the others received the designations of Titania and Oberon. The sizes of these distant objects are impossible to be measured; their periods of revolution and approximate distances from Uranus are as follows:

Name of Satellite.	Period.			Distance from Uranus.
	d.	h.	m.	Miles.
Ariel	2	12	29	120,000
Umbriel	4	3	27	170,000
Titania	8	16	57	280,000
Oberon	13	11	7	370,000

We now come to Neptune, the most distant known planet of all. When the illustrious Bouvard was forming his planetary tables about forty years after the discovery of Uranus, he found that it was impossible to reconcile the observations of that planet made since its discovery with the earlier observations made at various times when it was supposed to be a fixed star. He, therefore, in forming his Tables, rejected the latter altogether, and made use only of the former; but stated in doing so that he "left it to future time to determine whether the difficulty arose from inaccuracy in the older observations, or whether it depended on some extraneous and unperceived influence which may have acted on the planet." In a few years the question as to the nature of the cause was settled by the way in which Uranus refused to be confined to the course marked out for it by the Tables formed from the observations made between 1781 and 1821. It was evident, therefore, that an extraneous and unknown influence was acting upon its motions; nor could it

reasonably be doubted that the cause was the perturbing attraction of a planet moving at a greater distance from the Sun, and never (so far as was known) hitherto observed, being probably too faint to be included in any star-catalogues made before that time. The problem, however, of calculating the place of an unknown planet by the knowledge only of its influence upon another, staggered the few mathematical astronomers who were capable of attacking it, most of whom were already deeply engaged in labours too essential and exacting to bear an interruption of the length which its solution would probably demand. In 1844-5, however, it was taken up by two young mathematicians, one in England, the other in France, whose names are now known wherever astronomy is studied. The former, J. C. Adams, is at present one of the Professors of Astronomy at Cambridge; the other, U. J. Le Verrier, occupied for many years the post of Director of the Observatory at Paris, where he died in 1877. We cannot enter here into the history of their investigations. The approximate place of the unknown planet was determined by both; and when found, the actual place was between these two predicted places, but somewhat nearer to that indicated by Le Verrier, who indeed felt so certain of the accuracy of his final calculation that he suggested that the planet might be distinguished amongst the fixed stars in the neighbourhood by its disc. Meanwhile Challis * (then Plumian Professor of Astronomy at Cambridge and Director of the Observatory there) had been searching for it by its motion. Believing that the search would probably be long, he mapped down

* Prof. Challis died on the 3rd of December, 1882.

during several weeks all the stars visible in a considerable tract in the heavens around the place indicated by Adams, with the intention of comparing afterwards all these stars and tracing which of them had moved, which would thus give him several approximate places of the planet. But before he had completed his charts in this way, news arrived that Dr. Galle had seen the planet at Berlin, after looking for it in the place pointed out by Le Verrier. Its appearance at once suggested that it was the object of search, besides which it was wanting in a map (by Bremiker) of the stars in that part of the heavens, which had recently been received at the Berlin Observatory; and the next day (September 24, 1846) the alteration in its place placed its planetary character beyond a doubt. Not long afterwards the name Neptune (one of the names suggested for Uranus, when a designation for it was under discussion, it being felt that Herschel's **Georgium Sidus**, or Georgian Star, was not appropriate) was by common consent conferred upon this, the most distant known member of the planetary system.

Neptune occupies more than 164 of our years in revolving round the Sun, at a distance of more than 2700 millions of miles—about 30 times that of the Earth, as will be seen in our Table in Chapter IV. The eccentricity of its orbit is the smallest of those of all the principal planets, with the single exception of Venus. In size, it is somewhat larger than Uranus, its diameter amounting to about 36,000 miles, so that its volume or bulk is very nearly ninety times that of the Earth, but only about a fourteenth part of that of Jupiter. Its density is nearly the same as that of Uranus, and its mass is to that of the Sun in about

the proportion of 1 to 18,700. Being at so great a distance, it is not possible to perceive any spots or markings on its surface; so that its time of axial rotation is likely always to remain unknown to us, though we cannot doubt that some such exists, and that, like those of the other large planets, it is probably much more rapid than that of the Earth.

Only one satellite of Neptune is known. This was discovered by the late Mr. Lassell in the month of October, 1846, a very short time after the discovery of the planet itself. From its visibility at so great a distance it is probably the largest satellite in the solar system. Its distance from the centre of Neptune is about 220,000 miles; its time of revolution round him 5·87 days, or $5^{d}\ 21^{h}\ 8^{m}$. If this planet has other satellites, as is most probable, they must be much smaller, as none has been hitherto detected even with the powerful telescopes turned upon Neptune in recent years.

VIII. COMETS.

WHEN Kepler had shown, after a laborious investigation of the motions of Mars (extending it by analogy to the other planets), that the planetary orbits are ellipses, and when Newton had proved that this is a necessary consequence of their being attracted towards the Sun (placed in one focus of each ellipse) with a force varying inversely as the square of the distance from him, the theory at once suggested itself that comets might be simply bodies similarly moving round the Sun in ellipses of eccentricity so much greater than those representing the planetary orbits, that they would

only be visible in those parts of their elongated orbits which are nearest to the Sun and Earth; the law of equable description of areas, which would of course hold good in their case, causing them whilst in those parts of their courses to move much more rapidly than in any other part, so that the comets would be visible during a small portion only of their whole orbital revolutions. Newton applied these principles to the splendid comet of 1680 (visible a few years before the publication of the first edition of the 'Principia' in 1687), and found that it was moving in an ellipse of so eccentric a character as to approach very nearly in form to a parabola. It was conjectured by himself and by Halley that it might be identical with great comets recorded as having been seen in the years B.C. 44, A.D. 531, and A.D. 1106, and that the period was about 575 years in length. Subsequent investigations indeed have not confirmed this particular conjecture, but made it probable that the actual period of that remarkable comet (which made such an exceptionally close approach to the Sun) amounted to, not hundreds, but thousands of years, so that any previous appearance most likely took place before historic dates. But in regard to a fine comet which appeared two years later, in 1682, Halley was able not only to calculate the elements of its orbit, but to show that they were almost precisely the same as those of comets observed in 1531 and 1607; so far, at least, as could be decided by the observations accessible to him of these latter. Hence there were in this case good grounds to conclude that all these appearances were of one and the same comet, that its period was about 75 or 76 years in duration, and that it would probably

return in the year 1758 or 1759. It did so return, being first seen at that appearance by Palizsch, at Prohlis, near Dresden, on Christmas Day, 1758; and it has ever since been known by the name of the illustrious astronomer who had so confidently predicted its return. It passed its perihelion at that appearance on March 12, 1759, and, at the subsequent return, on November 16, 1835.

It would take far too much space for us to go into the history of comets generally. We here confine ourselves to narrating a few particulars about this and such others as have been proved to be moving in orbits of the form of ellipses of moderate eccentricity. A very large proportion of the comets which have been observed move in orbits practically undistinguishable from parabolas.

Of the former, Halley's comet itself is by much the most interesting. Its history has been traced with a very high degree of probability to a date nearly nineteen hundred years ago. In the year B.C. 12 Dion Cassius tells us of a comet seen about the time of the death of the great Roman general Agrippa, and the Chinese annals also mention a comet seen at a date corresponding to this; Dr. Hind has shown that this was probably an appearance of Halley's comet, and the first that can be traced. It is also probably referred to by Josephus as having been seen in the year A.D. 66, whan the Jewish rebellion broke out which led to the destruction of Jerusalem by the Roman army under Titus. The Chinese records also speak of a comet seen at that time, as well as of another in A.D. 141, which was probably also of the same. In A.D. 218, it appears to have been noticed both in China

and Europe, being followed (according to Dion Cassius) by the death of the emperor Opilius Macrinus, soon after his defeat at Irumæ, near Antioch, by Elagabalus. In the years 295 and 373 we are also able to recognize with much probability Halley's comet in accounts furnished by Chinese annalists; and in A.D. 451 it can hardly be doubted that a comet, observed not only in China but also in Europe (about the time of the great defeat of the Huns under Attila at Châlons-on-the-Marne, by Ætius and Theodoric), was identical with that which bears the name of our distinguished countryman. In A.D. 530 or 531, in the reign of Justinian, "a very large and fearful comet" was seen which (as we have already mentioned) Newton and Halley thought was an appearance of the comet of 1680. The more full observations of the Chinese which have become accessible to us since their time show that it is much more likely that it was a return of the comet of 1682. The appearances in A.D. 608 and 684 are, like some previously noticed, only recorded, so far as is known, in the Chinese annals. But in A.D. 760 a remarkable comet is stated to have been seen not only by their annalists, but by a Byzantine historian in the reign of Constantine Copronymus; Dr. Hind thinks it "little short of a certainty" that this too was a return of Halley's comet. Appearances of it also were probably seen both in Europe and China in the years A.D. 837 and 912; also in A.D. 989, as related in the Chinese records only. Now comes the year of the Norman Conquest in England. In the Bayeux tapestry is a representation of the people gazing at a comet which appeared soon after Easter, A.D. 1066, whilst England

was threatened with two invasions at once, which both took place in succession, but had very different terminations. This comet also was doubtless Halley's, which was also seen again in 1145, 1223, 1301, 1378, and 1456; in the latter year it seems to have been very conspicuous, and to have made a great sensation in Europe, alarmed at the progress of the Turks who had taken Constantinople only three years previously, making a final end of the remaining—the eastern—portion of the old Roman empire. The comet was observed at the succeeding return in 1531, but was apparently less brilliant; at any rate, we are dependent for our knowledge of its path on that occasion entirely upon the observations of Peter Apian, or Apianus (the Latinized form of his real name, which was Bienewitz). In 1607 this comet was observed by the illustrious Kepler; and it was, by a comparison of elements deduced from his observations in that year and Apian's in 1531, that Halley was led to the conclusion that both were in fact the same comet as the one observed by himself in 1682.

Such is in brief the history of this highly interesting comet. Another has recently been in view, the period of which is only a very little shorter than that of Halley, but whose history cannot be traced further back than its preceding apparition. On that occasion, in 1812, it was discovered on the 20th of July at Marseilles by Pons, the most successful discoverer of comets there has ever been; it became visible for a few days to the naked eye, and passed its perihelion on the 15th of September, the very day on which the conflagration of Moscow broke out, during the French occupation of that city under Napoleon. Its

period was several years afterwards calculated by Encke to be about 70½ years. Re-discovered by Mr. Brooks at Phelps, N. Y., on September 1, 1883, renewed observations showed that the period was slightly longer than as determined by Encke, and that it would arrive at perihelion in the January following, which it did on the 25th of that month. The next return will of course be due in 1955.

Although we propose to refer here only to comets which have actually been observed to return, the comparatively close approach of another likely soon to come under that category, leads us just to mention it. It was discovered by Olbers in 1815, and calculated by Bessel to have a period of about 72 years, so that it may be expected to return in 1887.

All other comets of this class have very much shorter periods. That known as Encke's is the most interesting. It was first discovered (by Méchain) in 1786, and again independently both in 1795 and 1805, being each time supposed to be a new comet. Pons also discovered it in 1818; and at that return Encke took it in hand, showed that it was moving in an orbit with a period of only about 3⅓ years, that it was identical with those just mentioned, and predicted another return in 1822. Both that and every subsequent return were observed, the last taking place about the end of the year 1881.

In many respects the next most remarkable of the periodical comets is, or rather was, that known as Biela's, the periodicity of which was detected at its return in 1826, when it was discovered by Biela at Josephstadt in Bohemia. But its first discovery was made in 1772 by Montaigne at Limoges, and it was

also independently discovered (being supposed, as in 1826, to be a new comet) by Pons in 1805. The period was determined in 1826 to amount to about 6¾ years, and the comet was accordingly observed again in 1832, in 1845-6, and in 1852. At the second of these appearances it was seen to have separated into two portions, the comparative brightness of which fluctuated considerably; the investigations of the late Prof. Hubbard of Washington afterwards showed that this disintegration probably occurred in the autumn of 1844. Both portions returned, but at a somewhat greater distance from each other, in 1852. But since then the comet has not been seen at all, at any rate as a comet, though it is supposed that a shower of meteors seen about the end of November, when the Earth passes through the comet's orbit, may form part of its dispersed material. The connection between comets and meteoric streams is now well established, and we shall allude to it in more detail in the next chapter.

A comet discovered by M. Faye at Paris in November 1843, and called from him Faye's comet, was found to be moving in a short elliptic orbit with a period of about 7½ years. It has been observed on every subsequent return, the last time about the end of 1880, when it passed its perihelion in January 1881.

The late Prof. d'Arrest of Copenhagen discovered a small comet at Leipzig in 1851. It was found to be moving in an ellipse with a period of about 6½ years, and was observed again (but only in the southern hemisphere, at the Cape of Good Hope) in the winter of 1857-8. In 1864 it was not seen, being unfavourably placed; it was, however, observed at the

returns of 1870 and 1877, but not at the recent one of 1883-4 (when it passed its perihelion on Jan. 13), on which occasion indeed there was felt to be small hope that it would become visible.

M. Coggia discovered a small comet at Marseilles in November, 1873, which was proved by Prof. E. Weiss to be identical with one discovered by Pons so far back as February, 1818, and to be moving in an elliptic orbit with a probable period of about 6¼ years. It was not, however, seen in 1880; another return will be due in the spring of 1886.

Pons discovered another comet at Marseilles in 1819, on the 12th of June, and Encke's investigations showed that it was moving in a short ellipse with a period of about 5½ years. It was not, however, seen again until 1858, when it was re-discovered as a new comet at Bonn by Prof. Winnecke, who, after he had determined its orbit, noticed its identity with the discovery made by Pons nearly forty years previously. Hence it is sometimes called Winnecke's comet, but Pons's seems a juster designation, adding the epithet "short-period" to distinguish it from our recent visitor, Pons's comet of 1812. This of 1819 and 1858 was observed again in 1869 and 1875, but not in 1864 or 1880, on which occasions its positions were very unfavourable for observation. Another return will be due, as in the case of the comet last-mentioned, in the year 1886.

Brorsen's comet was discovered by him at Kiel in 1846. Its period is also about 5½ years; it was, however, not seen in 1851 or 1863, but was observed in 1857, 1868, 1873, and 1879, so that another return will be looked for in the autumn of the present year (1884).

No less than three comets of short period have been discovered by M. Tempel, formerly of Marseilles, now Director of the Observatory at Arcetri near Florence. The first of these was found by him in 1867; its period is a little over 6 years; and having been also observed in 1873 and 1879, another return will be expected in 1885. His second periodical comet was discovered in 1873; its period is about 5¼ years, and it was also observed in the autumn of 1878, but escaped observation during the more recent return towards the end of last year (1883), when it was in perihelion on the 20th of November. Another appearance of this comet will be due early in 1889. A comet of short period was also discovered by M. Tempel in November, 1869; but its periodicity was not recognized until after it had been re-discovered by Prof. Swift, Director of the Warner Observatory at Rochester, N. Y., in 1880, in consequence of which it is usual to call it Swift's comet. The period is only about 5½ years in duration, so that an unobserved return must have taken place in 1875. Owing to its unfavourable position at the next return also, it is not likely that this comet will be seen again until 1891.

Mention should also be made of a comet discovered by Mr. Denning on the 4th of October, 1881, which is in all probability identical with one observed in 1819 (when it was discovered by Blanpain on the 28th of November), which was then thought to be moving in an elliptic orbit, with a period of about 5 years. But this has been so much lengthened by the effects of planetary perturbation that the period appears to be now about 9 years in length, so that the comet may be expected again in the year 1890.

The above comprise all the comets of very short period which have been known to return. One discovered by E. Pigott in November, 1783, was thought to be moving in an ellipse with a period of about five years; but this was somewhat uncertain, some thinking the period ten years, and, at any rate, the comet does not seem to have been observed either before or since. But there is a comet of somewhat longer period which has been seen at three returns to perihelion, although the first two of these were not consecutive or nearly so. It is known as Tuttle's, having been discovered by Mr. Tuttle at Cambridge, U.S., in January, 1858, when its periodicity was determined. It was shown that it had in fact been previously discovered by Méchain at Paris in 1790, and that its orbit was an ellipse with a period of about 13½ years, so that it had returned four times since the first discovery without having been noticed. It was, however, observed again in the autumn of 1871, passing its perihelion about the end of November; and another return will be due in the summer of 1885.

We have already (in the last chapter) made a passing reference to Lexell's comet of 1770. It was a truly unfortunate body in the way in which it was played fast and loose with by the giant planet, Jupiter. In 1767 it approached that body within a distance of only about one-sixtieth part of the radius of the orbit of the planet, which subjected it so powerfully to the influence of his attracting mass that the comet's orbit was completely changed. In 1770 it was discovered by Messier on the 14th of June, being at the time very near the Earth, which a few days afterwards it approached within a distance of little more than seven

times that of the Moon. Lexell calculated its orbit, and found that it was then moving in an ellipse with a period of about $5\frac{1}{2}$ years. It has, however, never been seen since, and was long known by the name of Lexell's lost comet. Its non-appearance, however, can easily be accounted for. At the return in 1776 its position was such that it was impossible that it should become visible, and before another return, or in the year 1779, it made another approach to Jupiter, much closer even than before, coming indeed nearer to the planet than the distance of its fourth satellite; this must have so completely changed its orbit again as to render its period afterwards something totally different from what it was before, and from what Lexell's calculations determined it to be in 1770.

There are a few other remarkable comets, surmised to have been seen at more than one return, but not capable at present of being classed as periodical comets, respecting which a few words may be said.

In papers communicated to the Royal Astronomical Society, and in his valuable work on "The Comets," attention was directed by Dr. Hind several years ago to the great similarity between the elements (so far as they could be determined from the descriptions given of its course) of the splendid comet of the year 1264, and those of the fine comet observed in 1556, about the time of the abdication of the Emperor Charles V. Hence it was thought extremely probable that these were two consecutive appearances of the same comet, and that we had before us in it the case of one returning after a sojourn of about three hundred years' duration in the depths of space. It was shown that the effect of perturbation would delay another return, and

on the whole it was thought most likely that this would take place about the year 1860. Neither then, however, nor at any time since, has the comet put in an appearance. Perhaps the cause may be an encounter with, or near approach to, some planet as yet unknown to us revolving round the Sun beyond the orbit of Neptune. Halley's comet when in aphelion is at about the same distance from the Sun as that planet; but a comet with a period of three hundred years would pass far beyond it.

The other case to which we alluded is that of the great comet, respecting the motions of which there was so much discussion in the autumn of 1882, and the question whether it had any connection with the fine comets of 1843 and 1880, or these with each other, or with any seen in bygone centuries. It is an undoubted fact that the elements of the comets of 1843, 1880, and 1882 were all very similar to each other; and it is probable that those of a comet seen in 1668, which was very imperfectly observed, were also similar. All made, when in perihelion, a remarkably close approach to the Sun, coming within a distance of 700,000 miles of his centre, or about 300,000 miles of his surface. Hence it was suggested that the tremendous attractive force exerted by the Sun upon the comet at so short a distance, might greatly shorten the period at each return, and lead before long to the comet's absorption into the Sun, producing an outburst of solar heat of incalculable amount. On the other hand, similarity of orbit is not a complete proof of actual identity, it being quite possible that there may be two or more comets moving along the same orbit at considerable distances from each other.

Mr. Neisŏn pointed out that great diminution in the length of period of a comet, supposing it to take place, must be accompanied by great diminution in the eccentricity of its orbit; and no such diminution can be traced on comparing the elements of the orbits of the comets of 1668, 1843, 1880, and 1882. Moreover, the best determinations of the orbit in which the comet of 1882 was actually moving, agreed in assigning about 750 years as its period. A suggestion of great interest has been made on this subject by Mr. Maxwell Hall of Kempshot, Jamaica, of which mention may be made in this place. A fine comet is recorded by Aristotle to have been seen in the winter of B.C. 370, when that philosopher was only thirteen years old, and still residing in his birthplace, Stageira. That comet appears also to have made a near approach to the Sun, and is stated to have separated into two portions; a statement which has acquired consideration from the analogy of Biela's comet. Now in the year A.D. 1106, a very splendid comet made its appearance, which evidently made a near approach to the Sun; as we have already mentioned, Newton and Halley conjectured that this comet was identical with the one observed by themselves in 1680, but that idea has been shown to be untenable, because the period of the latter was very much longer than about 575 years, as they supposed. Mr. Maxwell Hall's suggestion is, that it formed, in fact, a portion of the comet of B.C. 370, an unrecorded appearance of that portion having perhaps taken place about A.D. 368, and of the other or second portion about A.D. 381 or 382. He also supposes that this second portion may have undergone further disintegration on the return to the neigh-

bourhood of the Sun at the latter date; and that comets recorded in the Chinese annals as having been observed in the autumn of A.D. 1131, and in January of 1132, may have been respectively the re-divided parts of this second portion of the comet of B.C. 370. The comet, then, of 1843, he thinks, may have been, like that of 1106, a return of the first part of the original comet, the interval being nearly the same as that resulting from calculation; and the great comets of the spring of 1880, and of the autumn of 1882, were similarly, like the comets recorded in China in 1131 and 1132, returns of the second part of the original comet, assumed to have itself separated into two about 382, and to have been subsequently observed as two, first four months apart in time of perihelion passage, and finally thirty-two months (February 1880 to September 1882). Thus the interval between two successive returns of the same portion to perihelion would be nearly the same (about 740 years) as that resulting from calculation, which cannot be very exact. This theory is certainly very ingenious and plausible; according to it, no other appearance of any part of Aristotle's comet will occur until about A.D. 2580. It is not a very strong objection to Mr. Maxwell Hall's hypothesis that more than one appearance of a remarkable comet of which no record can be found, must, if it be true, have taken place in the latter part of the fourth century of our era; seeing that such records may not have been preserved by any extant historian. Independently of all other considerations, it is difficult to believe that the comets of 1843 and 1880 were identical with a period of 37 years, as no comet appeared which can have been the

same at any similar interval before 1843. As to the comet of 1668, the observations of it were so few and so uncertain that it is scarcely possible to draw any decided conclusion from them with regard to its path. The tail only was visible in Europe; and such knowledge of its orbit as we have is chiefly derived from a map of its course in the heavens, laid down from some very rough observations made in the East Indies, extending over a space of less than a fortnight in the month of March.

Of all the periodical comets, that which approaches nearest the sun is Encke's, which, when in perihelion, is very near the orbit of Mercury, (in the year 1835, it made a rather close approach to the planet itself, affording the means of determining a corrected value of its mass,) and even in aphelion does not recede so far from the Sun as several of the small planets. With one exception, the other short-period comets attain a distance from the Sun, when greatest, about equal to that of the orbit of Jupiter. Tuttle's, the period of which is nearly 14 years, is near the Earth's orbit when in perihelion, and wanders to a distance beyond the orbit of Saturn before reaching aphelion. The distance of Halley's comet from the Sun varies between 0·58 and 35·3 in terms of the Earth's mean distance; that of Venus, expressed in the same way, being (as we have seen) 0·72, and of Neptune, 30·05.

It does not come within the scope of this little treatise to speak at all of comets which move in parabolas, or in such elongated ellipses as approach in form to parabolas. Many of these have been computed to move in orbits of which a whole revolution is not completed until several thousands of years;

but in such cases the comets are under our observation for so small a proportion of their whole course that its length cannot be determined with great accuracy. The determinations of the period of revolution of the splendid comet of 1858 (known as Donati's), varied by more than a century on each side of two thousand years; the fine (first) comet discovered by M. Coggia in 1874 * has been computed to be moving in an orbit of more than ten thousand years' period; and a calculation of the orbit of the first comet of 1882 (discovered by Mr. Wells at Boston, U.S., on the 18th March), assigns about four hundred thousand years as its length of period.

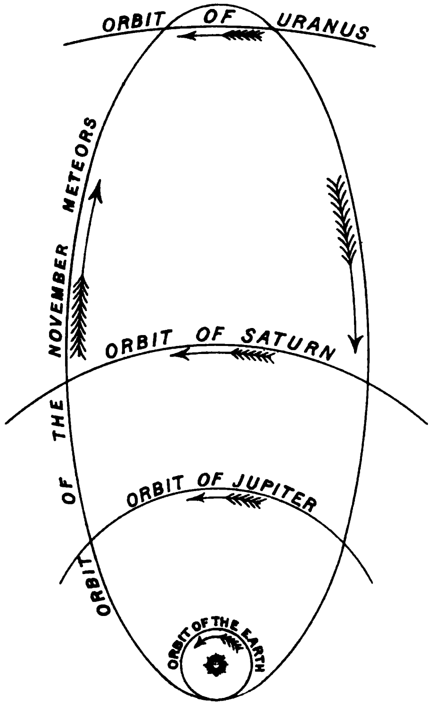
IX. METEOROIDS.

COMETS, as we have seen, have been for about two hundred years recognized as cosmical bodies moving in many cases in regular orbits round the Sun. That swarms of meteoric bodies to which the designation of meteoroids has been appropriately given, move in a similar manner, has been only known during a quarter of that period, or for about the last fifty years. The first definite establishment of the fact of the existence of such a swarm, is principally due to the labours of Prof. H. A. Newton of Yale College, New Haven, Connecticut, U.S., in the case of the November meteors. The recurrence of the shower as seen in the United States on the 12th November, 1833, the same day as a similar shower had been witnessed by Humboldt and Bonpland in South America thirty-four years before, on the 12th November, 1799, led to

* He discovered two comets (both at Marseilles) that year.

To face p. 49.

DIAGRAM ILLUSTRATING THE MOTION OF THE NOVEMBER METEORS.



The Comet discovered on December 19th. 1865 moves in the same orbit; the large arrows show the direction of motion of the Comet and meteors, the small arrows those of the planets.

a careful examination of previous accounts, and to the discovery that there was evidence that a shower radiates from the same point in the heavens about that time every year (slightly later, by about two days each century), but that it is especially brilliant and conspicuous at the end of each interval of thirty-three or thirty-four years. Several hypotheses were suggested which might account for this; but the investigation of Prof. Adams showed that one and one only of these would explain all the circumstances of the case. This, which is therefore the true explanation, is that the swarm of meteors, of which the November shooting-stars form a portion, moves round the Sun in a regular orbit, with a period of about 33¼ years, and that the perihelion of that orbit, where the meteors are of course nearest to the Sun, touches the Earth's orbit (as illustrated in the diagram on the accompanying plate). The Earth passing through that point of its orbit in the middle of November, meets some meteors on every such occasion; but the meteors being by far more closely aggregated together in a certain portion of their orbit, it is only every thirty-third year that the Earth encounters this portion, called the "gem of the ring." As this portion, however, is of some considerable extent along the line of the meteoric orbit (about, in fact, a fifteenth part of its whole length), a fine display, when it does occur, generally continues for two or even three years in succession. The orbital motion of the meteoroids, like those of many comets, is in a reverse direction to that of the planets, which of course greatly increases the relative velocity with which a portion of them enters the Earth's atmosphere, whilst the larger part of the

mighty stream sweeps on nearly towards the part of space which the Earth has left. The aphelion of their orbit, or the part which is at the greatest distance from the Sun, is a little beyond the orbit of Uranus. As a result of these investigations, another grand display of the November shooting-stars was predicted for the 13th day of that month in the year 1866; and this was duly verified, as doubtless many of our readers can themselves remember as eye-witnesses of it. Not long afterwards, the meteors seen about the 10th of August were subjected to a similar examination, with the result that they too move in an elliptic orbit round the Sun, and also in a reverse direction to that of the Earth and planets; but this orbit is much more eccentric than that of the November meteors, and though at perihelion it meets the Earth's orbit, at aphelion it stretches far beyond the orbit of Neptune.

These interesting discoveries were speedily followed by another, the priority in which belongs to Prof. Schiaparelli of Milan. It is that both these meteoric orbits are identical with those of two comets, which, therefore, must be regarded as having some very close and intimate connection with the meteoroids. The orbit of the meteors of November 13th has the same elements as that of a small comet, which was discovered by M. Tempel at Marseilles on the 19th of December, 1865, passed its perihelion on the 11th of January, 1866, and was found to have a period of 33¼ years. And the orbit of the meteors of August 10th coincides with that of another small comet observed in the year 1862 (the third comet of that year), which has been calculated to revolve round the Sun in a period of about 124 years, although this may

be a few years more or less in error. Do comets, then, consist principally of a congeries of meteors, which are gradually being scattered or dissipated along the whole extent of their orbits? If so, old reflections on the filmy and "almost spiritual" texture of a comet, because stars have been seen nearly through the central parts of some, are quite beside the mark, since there may be large vacuities between the separate meteoric bodies, the aggregate of which forms a particular comet. On the other hand, in many comets there must undoubtedly exist, at any rate at times, a large amount of matter in a state of vapour. The scattering of the meteoric particles along the line of the cometary or meteoric orbit must be much more complete in the case of the August than in that of the November meteors, since the degree of abundance of the former is far more uniform than that of the latter.

Another interesting fact, also confirming the above view, must be mentioned. We have already spoken of Biela's comet, and its having ceased to appear at the dates it was expected according to calculation. Now the Earth crosses the orbit of that comet on the 27th of November; and about that time showers of meteors have been seen to radiate from a point in the heavens, from which a body moving in the orbit of the comet would seem to approach. This was especially remarked on that date in the year 1872, when the Earth crossed the comet's orbit about three months after the comet itself should have passed that point. It was even suspected that a portion of the receding comet was afterwards seen in the opposite direction to that of the radiant point of the meteors;

but this remained somewhat uncertain, as it was difficult to reconcile the motion of that body with the theoretical motion of the comet. As the period of Biela's comet is about 6½ years, it will not be until 1885 that the Earth will again cross its orbit near the place where the comet would be, and where we may suppose the principal part of it, which is still in some state of aggregation, remains; so that in that year we may probably again expect a considerable display of meteors on the 27th of November.

X. THE FIXED STARS.

Having spoken, in the previous chapters, of those bodies, large or small, of which the motions can be traced so as to entitle us to regard them as regular members of the solar system, we shall in this give a short account of the motions and distances of those of the far more remote heavenly bodies coming under the general designation of fixed stars, of which anything certain can be learnt in this respect, concluding with a few words concerning the investigations which have been made as to the probable motion of our own system, as a whole, amongst them.

Those amongst the fixed stars which are bright enough to be visible to the naked eye have been watched from the most remote antiquity; and the greater part of the star-groups or constellations (as they are called), were formed and named in very early times. It was usual to designate any particular star (excepting a few very bright ones which have special names) by its place in the figure of the man, animal,

or monster, which the constellation in which it was located was supposed to resemble. The more accurate modern notation by the letters of the Greek and Roman alphabets in addition to and supplemented by (when the alphabets are exhausted, before which the numerals are **also** used) the Arabic numerals, dates from less than three hundred years ago.

No other knowledge was or could be gained about the fixed stars before the invention of the telescope, excepting the changes of brightness to which a few are subject, and the occasional and rare appearance of a temporary star never seen before. It is not in all cases easy to say, with regard to some of these, whether the accounts handed down to us really refer to a new star or to a comet. The most ancient record of the appearance of a new star, is that which is said to have burst out in the year B.C. 134, with a brightness sufficient to render it visible in the day-time, attracted the attention of Hipparchus, and led him to draw up the first catalogue of stars (which is, with some modifications, in the **Almagest** of Ptolemy) with the view of enabling future ages to trace with certainty any subsequent appearances or disappearances. An examination of the Chinese annals shows that the astronomers of that country also noticed this star, which seems to have been situated in the southern hemisphere, and in the constellation Scorpio. Another star is said to have appeared, as bright at one time as the planet Venus, in the year A.D. 389 (in the reign of the Emperor Theodosius); but from the accounts given by the ecclesiastical historians, it is evident that a remarkable comet was seen at the time to which this appearance is referred, so there can be

little doubt that the report of a new star having appeared is simply due to a misunderstanding of the description of the comet, which moved in the heavens from near the place where Venus then was to the constellation Ursa Major. A similar remark may be made with regard to new stars which are said to have appeared in the northern heavens in A.D. 945 and 1264. They were both, in fact, in all probability comets. We have already referred, in Chapter VIII., to the splendid comet of 1264 (the year of the battle of Lewes, and the capture of Henry III. and his son, Prince Edward, by the rebellious barons), which is thought with very great probability to have been an appearance of the comet seen nearly three hundred years afterwards, in the year 1556. But it is quite certain that a very conspicuous and remarkable new star *did* appear near the constellation Cassiopeia in the year 1572. The celebrated Tycho Brahé made most careful observations of this star (sometimes called "The Pilgrim"), and has left an elaborate account of it in a work devoted to the subject. He first saw it on the 11th of November of that year; its brightness, even then as great as that of Sirius, increased until it surpassed that of Jupiter. The star was for a short time visible in broad daylight, but soon began gradually to fade away, and by March 1574 had totally disappeared, after having been seen, with more or less brilliancy, during a period of about sixteen months. Another temporary star appeared in the year 1600, in the breast of the constellation Cygnus; and another in the right foot of Ophiuchus in the year 1604. Both these were observed by Kepler. The latter was at one time as bright as Venus; it continued visible for more than a

year, and disappeared in the month of October, 1605. The former never became brighter than a star of the third magnitude; but it appeared again, although much fainter, in the month of September, 1666, when it was observed by Hevelius. Studying attentively the stars of Cygnus in the year 1670, with the view of ascertaining whether that strange star would appear a third time, Father Anthelme, a French Carthusian of Dijon, was surprised to see, on the 20th of June, another new star of the third magnitude, very near the head of Cygnus. This star was observed both by Hevelius and by Cassini; it underwent several remarkable fluctuations of light during two years, then completely disappeared, and has not since been seen.

Within the last forty years, three remarkable instances have occurred of stars appearing almost or quite suddenly, of which there was no record of their previous existence. One of these was in the year 1848, when Dr. Hind noticed, on the 28th of April, a star of the fifth magnitude (very conspicuous to the naked eye), in a part of the constellation Ophiuchus, where he was certain that, so recently as the 5th of that month, no star so bright as the ninth magnitude was visible; nor is there any record of a star having been observed there at any previous time. From the date of its discovery it began continuously to diminish in brightness, and it is now visible only through a very powerful telescope. A still more remarkable, as well as more recent, case of the appearance of a temporary star (temporary at least as regards its visibility to the naked eye), is that of a star in the constellation **Corona Borealis**, which seems to have burst out quite suddenly on the 12th of May, 1866,

when it was first noticed by Mr. Birmingham of Millbrook, near Tuam, Ireland. It was at the time of discovery of the second magnitude, but diminished so rapidly as to be invisible to the naked eye by the end of the month. In the autumn of the same year it increased somewhat in brightness again, but not sufficiently so as to become visible without a telescope; and afterwards sank down to what we must suppose to be its normal or natural brightness. The last instance of the kind occurred in 1876, when Dr. Julius Schmidt (late Director of the Observatory at Athens, where he died last February) noticed on the 24th of November a new star, of the third magnitude, in the constellation Cygnus, which afterwards gradually faded away, ceasing to be visible to the naked eye in about a month, and is now only to be seen with the aid of a very powerful telescope.

We now regard the appearance or disappearance of a star simply as amounting to an increase of its brightness sufficient to render it visible when previously out of the reach of our vision; or, on the other hand, a diminution of brightness sufficient to render one which was visible no longer so, either to the naked eye or possibly even to the telescopic power applied to it. The expression, variable stars, is therefore now considered to be applicable to all such stars. The number of those which may be called regularly variable, being subject to regular changes in brightness of various degrees, is at present known to be very large, and is frequently being increased by fresh discoveries (these being usually of stars subject to smaller mutations of brightness); and there are also a few stars which undergo some remarkable irregularities of

change of this kind. The two most interesting cases of this latter kind are those of the stars called *o* Ceti and *η* Argûs. The former, sometimes called Mira Ceti, was first noticed as being subject to change in 1596, by Fabricius, who saw it of the third magnitude in August, and perceived in October that it had ceased to be visible. Bayer saw it in 1603, and Phocylides in 1638, noticing (which Bayer did not) that it was the same star subject to variability of brightness. The observations of Hevelius between 1648 and 1662 established its period, which is about 331 days in length; but (as we have said) the changes of brightness in this period are themselves of a very variable kind; neither is the period quite constant in length. It is usually visible to the naked eye for about six months of its period, and invisible during the remaining five months.

Halley was the first to suspect changes of brightness in that remarkable star in the southern hemisphere, *η* Argûs, which he had observed at St. Helena in 1677 as of the fourth magnitude. Lacaille in 1751 saw it of the second; and its changes from time to time since have been exceedingly irregular. In 1838, and again in 1843, it surpassed for a while all other stars in brightness, excepting only Sirius. After the latter date, it slowly but steadily diminished, and ceased to be visible to the naked eye in 1867.

Of the variable stars of short period, the most remarkable is that known as Algol or *β* Persei. Its usual magnitude is about the second, and as such it shines constantly and regularly for a period of about two days and a half; then it fades gradually down to the fourth magnitude, afterwards recovering its ordinary

brightness by a similar gradual increase, the whole amount of change taking place in about seven hours, so that the complete length of a period is somewhat less than three days; more accurately $2^d\ 20^h\ 49^m$. The most obvious and probable explanation is the regular interposition of an opaque body revolving round Algol, and cutting off at each revolution a portion of its light in the manner of a partial eclipse.

The above are the most conspicuous and easily-detected changes of brightness in the fixed stars, the others being either confined within narrower limits, or the stars being, even when at their greatest brightness, scarcely or not at all visible to the naked eye. About one hundred and fifty variable stars are now known to exist, and the application of photometry as an accurate means of measuring the amount of light of a star, will probably considerably increase this number. But it is not within our plan to describe or even enumerate these phenomena.

The next point on which something is to be said is that of the attempts which have been made to determine the parallaxes, and thereby the distances, of some of the fixed stars. This is a problem which completely baffled astronomers until less than fifty years ago. For so vast is the distance of even the nearest fixed star, that although we use the diameter of the Earth's orbit as a base, by comparing observations made at opposite parts of the year, nevertheless, the angle formed by it at the star (the half of which is the star's annual or heliocentric parallax) is so exceedingly small, as to be scarcely distinguishable from inevitable errors of observation. Maskelyne thought in 1760 that he had obtained, by comparing Lacaille's observ-

ations among themselves, a parallax of Sirius amounting to 4″; but afterwards it proved that the errors with which those observations were affected, rendered this or any conclusion of this kind from them, quite untenable. Another eighty years were to elapse before a really tolerably satisfactory determination was obtained; and this was in the case of a very different star, much less bright, and indeed only just visible to the naked eye, known as 61 Cygni. Attention was directed to this star as being probably much nearer us than others, in consequence of its unusually large proper motion in the heavens, which carries it through an arc in the celestial sphere of about six seconds every year. Taking advantage of the circumstance that there are two other small stars (61 Cygni is itself double) in its close neighbourhood, which, not sharing in this motion, are probably much further off, Bessel commenced, in 1837, a series of observations of this star at Königsberg with the view of determining its parallax relatively to that of the small neighbouring stars; as their parallax might fairly be considered insensible, the result would be practically the value of the parallax of 61 Cygni, or of the two stars composing it. In the year 1840 he was able to announce that this quantity was thus in fact measurable, and amounted to about 0″·35. Later observations by other astronomers have essentially confirmed this; rendering it probable indeed that the accurate value is a little more than this, being very nearly, if not quite, 0″·5. The resulting distance of 61 Cygni from the solar system is about 40 billions of miles. Meanwhile, several series of observations of a bright star in the southern hemisphere, *α* Centauri, have proved that

its parallax is probably the greatest of all the fixed stars; some measures indeed make this nearly equal to a second of space, but the best determination appears to be that recently made by Dr. Gill at the Cape of Good Hope, which amounts to $0''\cdot75$, indicating a distance of somewhat less than 30 billions of miles. Several other stellar parallaxes have since been measured with more or less satisfactoriness. Those of Sirius and Capella each seem to be about $0''\cdot3$; one small star in Lalande's catalogue (No. 21,185) has yielded a parallax equal to that of 61 Cygni, or about $0''\cdot5$, and that of another (No. 21,258) has been found to be about $0''\cdot3$. Prof. Otto Struve has recently published a determination of that of the bright star Aldebaran (α Tauri), making it about $0''\cdot5$, nearly the same as that of 61 Cygni.

In speaking of this last, we used the expression double star; we must now distinguish the two classes of stars which come under that designation. A star which appears like a single star to the naked eye, but when viewed with a telescope is seen to consist of two so near as not to be separated by the unaided vision, is naturally called a double star. But the fact of there being two stars in such close proximity does not of itself prove that there is any connection between the two. They may be merely optically double, that is, only appearing double because the individual stars are situated nearly in the same line of sight. But Sir William Herschel's persevering surveys of the heavens revealed to him so large a number of these apparently double stars, that the suspicion arose that in many cases some physical connection existed between the separate stars composing them. In the year 1782 he

commenced the practice of carefully observing and recording the relative positions and distances of the stars which he had noticed as being apparently closely double. When these values were determined again, after an interval of some years, it clearly resulted that in many cases the components of a double star had a distinct motion with reference to each other. To these, then, the name of binary stars has been given, to distinguish them from such as are only optically double; and as time has gone on, and a constantly larger number of observations has been made and compared, more and more of the latter have come under the former category. Sir William Herschel's first paper on the subject is contained in the *Philosophical Transactions* for 1803, in which he remarks that the series of observations, of which he there gives an account, is distributed over a period of twenty-five years, and goes to prove that many of the stars whose mutual positions and distances had been measured by him, "are not merely double in appearance, but must be allowed to be real binary combinations of two stars, intimately held together by the bond of mutual attraction." A very great number of double stars was examined by the late M. Struve at Dorpat and Pulkowa, and a catalogue of his results (numbering 3134 stars) was published at St. Petersburg in 1837. The high interest attaching to the subject has led many skilful observers to devote a large amount of attention to it since the publication of Herschel's first papers. The relative motion of many of the binary stars has been proved to be of the nature of a regular orbital revolution of one of the components round the other. Among these, the most interesting cases are those of

ζ Herculis, ξ Ursæ Majoris, and 70 Ophiuchi, in which the periods of revolution have been determined with very considerable accuracy to amount to about 34, 61, and 94 years respectively. The shortest is that of δ Equulei, which Mr. Burnham from his observations with the great 18½ inch telescope at Chicago has recently found to be less than eleven years. Much longer than any of these, and therefore somewhat less certain, are the periods of revolution which have been calculated for those interesting and long-known double stars γ Virginis, γ Leonis, and Castor. The first of these amounts to about 180, the second to about 400, and the third to nearly if not quite 1000 years. Accurate and long-continued observations of the proper motions of the larger stars which are regularly made at observatories have disclosed, by means of the irregularities of these motions, more than one instance of the disturbance of a star by an unseen companion, so that the fact of the star being binary was only discovered by this means. Such was the case with the brightest of all the fixed stars, Sirius; but the disturbing companion was afterwards detected as a small star near it, only visible in a powerful telescope. But Procyon, the principal star in Canis Minor, is also subject to a similar irregularity of proper motion; and one which would seem to result from the fact of its moving in an orbit round a companion either opaque or possessing too feeble a luminosity to be within our perception by the best optical means at present available; the period of revolution in this case amounts to about 40 years.

We have alluded more than once to the subject of stellar proper motion. Nearly all the stars, when observations of them made at considerable intervals of

time are compared together, are found to be endowed with a certain amount of proper motion. We shall consider presently whether the whole of this is in all cases due to actual motion of the stars in space; but certainly a considerable part of the proper motions which are exceptionally large must be so. It has already been mentioned that attention was directed to 61 Cygni as being probably nearer us than most of the fixed stars, by the circumstance of its having a very large proper motion, amounting to about five seconds in a year. Another star, still less bright, and having no designation but a number in a star catalogue (1830 in that of Groombridge), has a proper motion even larger than this, being seven seconds in amount, or nearly so; but this star does not appear, like 61 Cygni, to be much nearer the solar system than others. Several stars have proper motions a little smaller than this, each amounting to between four and five seconds. But the great mass of stars are endowed with proper motions much smaller than these, and only to be recognized by comparing different observations made with great precision, and separated by considerable intervals of time. From a discussion of several of the best determined of these, Sir William Herschel considered that they were in part produced by a movement of our sun and solar system in space amongst the stars; and he indicated a point in the heavens in the constellation Hercules as that towards which this movement is carrying us. Subsequent investigations on this subject have been made by other astronomers; one of the latest being that of Sir George Airy in 1859, applied at first to about 300 stars, and afterwards extended by Mr. Dunkin to 1167 stars, 819 of which

are in the northern and 348 in the southern hemisphere. All these investigations agree to the extent of placing the apex of the solar motion in the constellation Hercules, and therefore not far from the point first indicated by Sir W. Herschel in 1783. Theories have been formed with regard to a central point round which the solar motion has been thought to be performed; and the late Prof. Mädler of Dorpat, founding his conclusion also on a comparison of a number of stellar proper motions, considered that he had shown that this was round a point in the heavens situated in or near the group of stars known as the Pleiades. To this theory, the name of the "central sun hypothesis" has been given; but Mädler protested that he had never suggested that there was a central sun or other body in the place round which the observations indicated, as he thought, that our sun and system were moving. His theory has not met with general acceptance amongst astronomers, and it is felt that such speculations are at least premature, and that a larger number of proper motions than are as yet available, resulting from observations extending over very long intervals of time, must be compared and discussed before such a problem can be attacked with any reasonable prospect of success.

The investigations of Mr. Proctor have shown, by a comparison of a very large number of stellar proper motions, that there are several remarkable instances of many stars, grouped together in so peculiar a manner as to have attracted attention from early times to their configuration, which are moving in apparent directions and velocities in the heavens very similar to each other, thereby suggesting the idea of some real con-

nection between them, enormous as must be their mutual distances. These motions, similar in each of the groups or configurations in question, are very different from those in other groups, and must be due to some actual joint motion of the stars of which each is composed. To this motion Mr. Proctor has given the name of *star-drift.*

Something perhaps will be expected here concerning star-clusters and nebulæ; but it does not come within our scope to say more than a very few words. Casual inspection of the heavens shows that whilst many of the fixed stars are arranged in groups or constellations which imagination has likened to the forms of animals and other objects (some of these in strings of various twists suggesting the idea of serpents or dragons), and that these groups are spread out over regions of the sky of many degrees of extent, in certain places a group of stars is seen arranged close (sometimes very close) to each other, so as to form a sort of cluster. The most remarkable of these clusters is that called the Pleiades in the constellation Taurus; every eye can detect six stars in this, some persons with unusually acute vision can see several more, and with a moderately good telescope at least a hundred become visible. Near this, in the same constellation, is a more scattered group called the Hyades, resembling a letter V; and another in the constellation Cancer, called Præsepe, is visible to the naked eye, but not as a cluster of stars, which a telescope shows it to be; without such aid it looks like a dullish spot or nebula in the sky, not well seen unless the night is very clear. The telescope, whilst it shows this and many other nebulous or cloudy-looking masses to be composed of

very distant or very minute stars, reveals the existence of many more not visible to the naked eye at all. The most remarkable of all the nebulæ is that in the constellation Orion, in the part of it called "the sword," and near the star θ Orionis. Although this gigantic object contains a large number of telescopic stars, yet there is now reason to believe that a portion of the light which we receive from it and from some other nebulæ is due to glowing gas.

XI. SHORT SKETCH OF THE HISTORY OF ASTRONOMICAL DISCOVERY.

THE greatest name amongst the ancient astronomers is that of Hipparchus, who was a native of Nicæa, in Bithynia, but made most of his observations in Rhodes. He was the first to form a systematic Catalogue of stars, induced to do so by the appearance of a new star in the heavens, which is thought to be the same as one recorded in the Chinese annals as having appeared in a year corresponding to B.C. 134, in the constellation Scorpio. The most probable date of the death of Hipparchus is B.C. 120. His Catalogue is only known to us by its being incorporated, with some modifications, into the great work of Ptolemy, Μεγάλη Σύνταξις, which we, in imitation of the Arabian astronomers, usually call the Almagest. Ptolemy, whose name is principally recognized by its connection with the Ptolemaic system, died in the year A.D. 170. Amongst the Arabian astronomers the greatest name is that of Albatenius,*

* So called from his birthplace, Baten, in Mesopotamia, (Al, the definite article.) His real name was Mohammed Abdallah.

who flourished in the ninth century of our era. Another Catalogue of stars was made by, or rather under the auspices of, the Mongol prince, Ulugh Beigh * (as he is generally called), grandson of the famous Timour; it was formed from observations made at Samarkand, about the year A.D. 1433. Towards the end of the same century, the labours of Peurbach and Müller † prepared the way for Copernicus, who showed the simple explanation of the planetary motions which resulted from supposing the sun to be placed in the centre of the system. His work, 'De Revolutionibus Orbium Cœlestium,' was published in 1543, in which year the illustrious author died. The foundation of the true theory of the solar system was thus laid, but the time for its establishment had not arrived. It was rejected by the great Danish astronomer, Tycho Brahé, in favour of a system called from him the *Tychonic*, by which the Moon and Sun were supposed to revolve round the Earth, and the planets round the Sun. Tycho's observations, however, furnished the means by which, less than twenty years after his death, Kepler deduced the laws according to which the planetary motions are performed. It was in the year 1618 that he discovered his third and last law, which shows the mutual correspondence existing in the motions of all the planets, and proves (though it was reserved for the genius of Newton to demonstrate that this consequence was involved in it) that they obey the same law of force directed towards the sun. Mean-

* His real name was Mirza Mohammed Taraghai.

† Usually called Regiomontanus, the name of his birthplace translated into Latin.

while the equally famous Galileo * had been discovering the smaller system of moons which revolve round Jupiter as the planets do round the Sun, confirming by that and by other discoveries the truth of the Copernican system, and establishing the laws of motion, without a knowledge of which further progress in astronomy as a science was impossible. Galileo died in 1642; and in the same year was born Newton, the prince of philosophers, who discovered the law of gravitation, and showed how by its means the most important of the lunar and planetary motions could be explained. This was made possible by Picard's determination in France of the true size of the Earth, and by Flamsteed's observations of the Moon at Greenwich, which commenced in 1676, the observatory there having been founded the year before. Newton's great work, the 'Philosophiæ Naturalis Principia Mathematica,' was published (as we mentioned in a preceding part of this treatise) in 1687. Meanwhile Huygens had discovered one, and Cassini four, of the satellites of Saturn; and the former had explained the ring-like form of the appendage to Saturn, the existence of which had been first noticed by Galileo. It was not until some time after the death of Newton (which occurred in 1727) that his theory was further developed and shown to be capable of explaining not only the principal courses, but the smaller modifications, of the planetary motions. This is due to the labours of several eminent mathematicians, but especially to those of Lagrange and Laplace. The 'Mécanique Analytique' of the former was published in 1787, and

* Galileo Galilei is better known in England as Galileo than by the family name of Galilei.

the 'Mécanique Céleste' of the latter was completed in 1825.

But towards the end of the eighteenth century arose an astronomer, Hanoverian by birth, but English by adoption, who not only extended what had previously been supposed to be the boundary of the solar system, by the discovery of Uranus in 1781, but, turning with unwearied diligence upon the sidereal heavens the powerful instrumental means which were the work of his own hands, acquired for mankind a knowledge of the distribution and motions of the stars and worlds beyond our own system, which opened a new era in the history of astronomy. Sir William Herschel died in 1822, after having been elected the first President of the Royal Astronomical Society, which was founded in 1820. The Society published in 1827 a compiled Catalogue of Stars, which was the standard work of reference on the subject until it was superseded by the Catalogue of the British Association, published in 1845. Soon after this, the boundary of the solar system was still further enlarged by the famous discovery of Neptune (of which we have spoken in Chapter VII.) in 1846; and in the following year Sir John Herschel published the results of his observations at the Cape of Good Hope, where he had been devoting some years to a diligent scrutiny of the stars and nebulæ only visible in the southern hemisphere, similar to that, initiated by his father and extended by himself and others, of the portion of the heavens which is visible in England. Early in the present century four new planets were discovered, revolving between the orbits of Mars and Jupiter, which are so much smaller than all the others, that distinct terms—planetoids or

asteroids—were suggested for them. But as they differ from the others only in respect of their comparatively minute size, it is now more usual to call them small or minor planets. They remained four in number until 1845, when a fifth was discovered, and from that time (see the Table in Chapter VI.) discovery has been continuous, until at the present time no less than 237 members of the group are known to exist, and probably there are many more, although most of the later discoveries require very powerful telescopes to see them. The number of known bodies of the solar system has been further increased by the discovery of several more satellites (including two very tiny ones revolving round Mars, discovered in 1877), all which are referred to in previous parts of this volume. And, as we have already mentioned (in Chapter X.), the accurate observations of modern times have also enabled astronomers at last to determine the approximate distances of some of the fixed stars; the nearest, α Centauri, being about 300,000 times as far off as our own Sun (we say *our own* Sun because the fixed stars must be of the nature of Suns themselves, *i. e.* shining with their own light, for reflected light would not reach us from such enormous distances), or not much less than thirty billions of miles.

It is now about twenty-five years ago that a new branch of astronomy was opened up by the analysis of the light of the heavenly bodies by means of the spectroscope. This commenced with the investigations of Kirchhoff and Bunsen in 1859, but was brilliantly followed up by Dr. Huggins and the late Dr. W. A. Miller, and subsequently by others. Not only has it enabled us to learn much of the chemical

constitution and condition of the worlds and other luminous objects both in and beyond our own system, but its later developments have revealed motions of several of the stars in the line of sight (in some cases approaching, in others receding from us), which could not be recognized in any other way. One very interesting discovery made by the aid of spectrum analysis is that the light of many of the nebulæ (as was alluded to at the end of our last chapter in the case of the great nebula of Orion) does not proceed from stars, as was once supposed, but from incandescent or intensely heated matter in a gaseous condition. But, although in even the shortest sketch of the history of astronomy, mention of this subject could not be wholly omitted, it does not fall within our scheme to enter upon it in any detail here.

ALPHABETICAL EXPLANATION OF THE ASTRONOMICAL WORDS AND TECHNICAL TERMS USED IN THE FOREGOING TREATISE.

APHELION (properly ap-helion); from the Greek, ἀπό, *from*, and ἥλιος, *the Sun;* the point in a planet's orbit where it is farthest from the Sun.

ASTRONOMY, the science of the stars; from Greek, ἀστήρ, *a star*, and νέμειν, *to distribute, disperse*, (whence Greek, νόμος, *a law*.)

BINARY, double, two-fold; from Latin, binarius, *consisting of two things.* Applied technically to two stars which are comparatively near, and found to be in physical connection with, each other.

BISSEXTILE, a name for leap year, derived from the Latin. The Romans added the intercalary day in leap year by reckoning the sixth day before the calends of March (corresponding to our 24th of February) twice over, calling the second day *bissextus dies*, whence the leap year itself was called *bissextilis annus*.

COMET (Latin, cometa), from Greek, κόμη, the hair of the head, the first idea of comets being that they were stars with hair-like tails.

CONGERIES, a mass of particles; strictly a Latin word; congeries, *a heap*, from con-, for cum, *together*, and gerere, *to carry*, *bring*.

CONSTELLATION, a group of stars; from Latin, con-, for cum, *together*, and stella, *a star*.

DENSITY, from Latin densus, *thick*, *close*, cognate with Greek δασύς, *thick*. Technically applied to the degree of closeness with which matter is contained in a given bulk or size. *Mass* is the quantity of matter contained in a body, so that if this matter be compressed into a smaller space, the mass will remain the same whilst the density will be increased in proportion to the smaller space in which the mass is contained.

DISC, or disk, a round plate (Latin, discus, *a quoit*, *a plate*), from Greek, δίσκος, *a quoit*, connected with δικεῖν, *to cast*, *throw*. Technically applied to the round visible surface of the Sun or Moon, or (as seen with a telescope) of one of the large planets.

ELLIPSE, an oval figure; Latin, ellipsis, Greek, ἔλλειψις, from ἐλλείπειν, *to leave in* or *behind*. A parabola is formed by cutting a cone parallel to one side, the edge of which section is a parabola; an ellipse is formed by cutting the cone by a plane which makes a smaller angle with its base than one parallel to either side, whence the word.

ECCENTRICITY, a departing from the centre, or the amount of such departure; from Greek, ἐκ, *out*, and κέντρον, *centre*. Technically applied to the proportion which the distance between the centre and one of the foci of an ellipse bears to the semi-major axis, or half the longer diameter.

FIXED STARS. The stars beyond our solar system are called *fixed*, because being at such enormous distances, they appear to us (after allowing for the effects of the known motions of the Earth) always in the same or very nearly the same places in the visible heavens. The comparatively small motions which modern astronomy has discovered in some of them are called their *proper motions*.

FOCUS, a place where rays of light meet, from Latin, focus, *a hearth*, or *burning-place*. An optical term transferred to mathematics and astronomy. The focus of a parabola is the point within it to which all rays of light falling upon it from a great distance and parallel to its diameter converge after reflection. An ellipse has two foci; all rays of light diverging from either focus would, after reflection at the ellipse, converge to the other focus. All the planetary orbits are ellipses with the Sun in one focus; those comets which move in a parabola have the Sun in its focus, but these do not return after having been once seen.

GREGORIAN RECKONING. So called from Pope Gregory XIII., who introduced that reckoning of the calendar in 1582, by which there are exceptions in making every fourth year a leap year. If the year A.D. is divisible by 100 without remainder, it is not a leap year unless it is also so divisible by 400, when it is. Thus, A.D. 1900 will *not* be a leap year.

JULIAN RECKONING. So called from Julius Cæsar, by whom it was introduced and ordered to be observed. By it, *every* fourth year was a leap year, so that if the year A.D. was divisible by 4 without remainder, such year was *always* a leap year. The Julian reckon-

ing was generally observed until the year 1582, in England until 1752, and is still observed in Russia and Greece.

METEOR, strictly any appearance in the sky; from Greek, μετέωρος, raised up above the earth, soaring in the air (μετά, *among*, and ἐώρα, collateral form of αἰώρα, *anything suspended*, from ἀείρειν, *to lift*, *raise up*). Technically applied to luminous bodies sometimes seen moving in the upper regions of the earth's atmosphere, their motion through which makes them luminous. They are sometimes called shooting-stars.

METEOROIDS, from Greek, μετέωρος (see above under *Meteor*), and εἶδος, *form*. Technically applied to those meteors which have been discovered to move in large streams round the Sun, and appear like meteoric showers when the Earth is passing through them, radiating from the point in the heavens towards which the Earth is then moving. The August meteoroids are often called Perseids, because they radiate from a point in the constellation Perseus; the November meteoroids Leonids, because they radiate from one in the constellation Leo.

NEBULA, properly a Latin word, cognate with the Greek, νεφέλη, *a little cloud;* technically applied to a mass of matter (sometimes consisting of a cluster of very distant stars) which resembles a small cloud in appearance.

NODE, from Latin, *nodus*, a knot. Technically used for the points in the orbit of a planet where it crosses the plane of the Earth's orbit.

OPAQUE, originally a French word; from Latin, opacus, *shady*. Technically applied to a body which

is not self-luminous or transparent, and can only become visible by reflecting rays of light which fall upon it. As all the planets and satellites in the solar system are opaque, and receive their light from the Sun, they cast conical shadows behind them on the side opposite to that body. When one of the satellites as it moves becomes partially or wholly enveloped in the shadow of the planet round which its orbital motion is performed, it is said to be eclipsed, partially or totally, as the case may be. The shadows of the satellites are too small ever to cover wholly the bodies of their planets when they are interposed between these and the Sun. Thus the shadow of the Moon can at most cover at a time only a portion of the Earth about 170 miles in diameter, and in that portion only does the Sun appear to be totally eclipsed for a duration never exceeding a few minutes; over a much larger region on either side of this there is a partial eclipse.

PARABOLA (see above under *Ellipse*); from Greek, παρά, *beside*, and βάλλειν, *to cast, throw;* of similar origin to "parable," but technically used for the figure formed by a plane cutting a cone parallel to one of its sides, the edge of which section is a parabola.

PARALLAX, from Greek, παράλλαξις (παρά, *beside*, and ἀλλάσσειν, *to change, alter*), the apparent change in the place of a heavenly body produced by a real change of place of the observer. Technically, as applied to the bodies of our own system, it means the difference between their places as actually seen by us, and as they would be seen from the centre of the earth; as applied to the fixed stars, the difference between their

places as seen by us on the Earth, and as they would be seen from the Sun, the centre of the Earth's motion.

PERIHELION, from the Greek, περί, *around*, and to ἥλιος, *the Sun;* the point in a planet's orbit where it is nearest to the Sun.

PHASE, from the Greek φάσις, an *appearance*. Technically applied to the varying apparent shape of the Moon and some of the planets, in consequence of a larger or smaller part of that half of their surfaces which is illuminated by the Sun being turned towards the Earth. Mercury and Venus, which move in orbits round the Sun within that of the Earth, exhibit all the phases of the Moon; but the planets which move in orbits beyond that of the Earth, can only become slightly gibbous in appearance. Indeed it is only Mars, the next planet outwards to our own, that can take that form to a sensible extent, the Earth being so near the centre of the orbits of the others (in proportion to the diameters of those orbits) that we practically have always the illuminated half of their surfaces turned towards us.

PLANET, a wandering star; from Greek, πλανήτης, *a wanderer*, a lengthened form of πλάνης, of which the plural πλάνητες was especially used to signify the planets. Technically applied to the solid spherical bodies of the solar system which move in regular orbits round the Sun.

SATELLITE, a follower, attendant, from French, *satellite*, a sergeant, or yeoman of the guard; Latin, *satellitem*, accusative case of *satelles*, *an attendant, life-guard.* Technically applied to the smaller bodies

(formerly sometimes called secondary planets) which move round some of the large planets, as the Moon does round the Earth, of which it is a satellite.

SELENOGRAPHY, a description of the Moon's surface, from Greek, σελήνη, *the Moon*, and γράφειν, *to describe;* similar to Geography as applied to the Earth, from γῆ, *the Earth*, and γράφειν.

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